Teaching STEM in four Australian Primary Schools

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Abstract

This study investigates the knowledge that highly skilled teachers draw on to design and assess interdisciplinary Science, Technology, Engineering and Mathematics (STEM) learning experiences for their primary school students. Improving the knowledge and practice of teachers' integration of STEM subjects in schools is currently a national priority in Australia and in more than twenty countries around the world. STEM is important in primary schools because students' learning experiences in this area influence their career trajectories. As there is limited STEM research in primary classrooms, this study adds to a growing body of STEM project based learning (PBL) literature, and pioneers an investigation into the use of frameworks: technological, pedagogical, and content knowledge (TPACK) framework, gold standard project based learning, and the Learning by Design model, for researchers to explore the STEM practice and assessment of teachers. In addition, the findings of this study include four teacher-participants: knowledge and adoption of a STEM PBL approach, understanding of the value of students' STEM knowledge and skills in planning, and extensive knowledge of formative assessment strategies. Finally, it draws attention to a range of potential concerns about poorly implemented STEM, including: possible loss of students' traditional disciplinary knowledge and the importance of balancing subject-based disciplinary knowledge and the use of interdisciplinary gold standard PBL.

Declaration

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed: 

Mr. Aidan Cornelius-Bell

Date: 30/11/2017

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Chapter 1: Introduction

This thesis reports the process and outcomes of a study into the practices of teachers responding to a new emphasis on science, technology, engineering and mathematics (STEM) education in Australian Primary Schools. There is significant impetus to improve teachers’ knowledge and practice in the integration of STEM subjects in schools (e.g. Marginson, Tytler, Freeman, & Roberts, 2013; Sanders, 2008; Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008).

A review of international literature identifies a gap in research about primary school teachers’ knowledge of planning and approaches to interdisciplinary STEM, and their assessment of students’ STEM learning. The literature review also observes a growing body of literature on STEM project-based learning (PBL) (Capraro & Slough, 2017; Rosicka, 2016) highlighting a PBL approach to STEM. This research lacks an Australian context.

Aim and research questions

The aim of this study was to investigate the knowledge, pedagogical approaches, and assessment practices of highly skilled primary school teachers, teaching interdisciplinary STEM.

This aim informed two research questions:

1. How do highly skilled teachers plan interdisciplinary STEM learning experiences for primary school students?
2. How do highly skilled teachers assess students’ learning in STEM and what is the evidence they use to evaluate their impact on student learning?

Significance of the study

For two main reasons the proposed study is significant. Firstly, this study will contribute to the research literature by investigating how four highly skilled educators plan, assess and provide supporting evidence of students' STEM learning. The findings of this study contribute to the current understanding about how highly skilled educators are facilitating and assessing student learning, through the integration of STEM learning areas and using real-world problems to promote inquiry learning, problem solving, thinking skills, and a focus on science, literacy, and numeracy. The data, findings and discussion will be drawn from individual interviews about classroom-centred evidence. Secondly, Flinders University College of Education, Psychology and Social Work is investigating the development of a STEM specialisation to build the capacity of primary pre-service teachers preparing to teach in this area of employer demand. There is an opportunity for this study to provide some insight in the design of the curriculum for the series of STEM specialisation topics through the provision of examples of evidence-based practices of the four participants. This study develops reports for each participant drawn from interviews and annotated samples of student work that exemplify evidence-based practice of teachers in primary school STEM teaching.

This thesis continues, in Chapter 2, with an extensive review of relevant literature, introducing frameworks and models, and content, knowledge and skills teachers draw upon in designing and assessing interdisciplinary STEM learning experiences for their students. Chapter 3 introduces the research design for this study, a qualitative-interpretivist approach. Chapter 4 elaborates the results of the empirical study. Chapter 5 discusses the findings of the study, and compares the results to the findings of the literature review, including the introduced frameworks. Chapter 6 concludes the thesis and identifies areas for further research.

Chapter 2: Literature Review

Despite the proliferation of commentary and literature, policy, and economic influence in science, technology, engineering and mathematics (STEM) education, little is yet reported about the pedagogical practices of primary school teachers and the evidence they use to evaluate their impact on student learning of STEM. This literature review is presented in four parts relevant to this study. The first introduces the TPACK framework, as a theoretical lens to understand teachers' technology, pedagogy and content knowledge (TPACK) (Mishra & Koehler, 2006, 2008) when planning interdisciplinary STEM learning experiences for primary school students. This section explores the variety of pedagogies available in discipline-specific learning areas, the content knowledge of the curriculum, and the information communication technology tools, and technological knowledge that teachers integrate in their STEM teaching. The second then introduces what authors are calling the gold standard project-based learning (Larmer, Mergendoller, & Boss, 2015) approach, a second theoretical lens used in conjunction with the TPACK, to understand the STEM planning of teachers. In the third, the Learning by Design (Kalantzis & Cope, 2008) model is introduced as a way of understanding teachers' consideration of the evidence of the knowledge their students will develop when engaging in STEM learning. Finally, extant assessment practices are explored to address teachers' assessment of students' learning in STEM, and the evidence they use to evaluate their impact on student learning.

Diversity of STEM definitions

There is ambiguity in the literature associated with the use of the STEM acronym[1], this section outlines the definition of STEM and STEM skills terminology used in this study.

The individual disciplines that comprise STEM may interact in markedly different ways, depending on the classroom, country, context, teacher and students (Marginson et al., 2013). The policy push toward interdisciplinary practice raises fundamental questions about the nature and purpose of science, technology, engineering and mathematics subjects and their relationship to one another, the skills required to master them, and the future for which they aim to prepare students (Marginson et al., 2013). There are different definitions and ways of conceptualising STEM teaching, ranging from describing discrete learning areas; the emergence of a new subject that incorporates elements of existing learning areas; through to an interdisciplinary approach that bridges a combination of two or more of the subject-areas within science, technology, engineering and mathematics (Education Council Secretariat, 2015; Sanders, 2008; Tytler et al., 2008). Sanders (2008) provides a helpful definition of STEM as "*approaches that explore teaching and learning between/among any two or more of the STEM subject areas*" (p. 21). The definition of

[1] STEM is not the only extant configuration of the acronym. Among other configurations: STEAM as **s**cience, **t**echnology, **e**ngineering, **a**rts and **m**athematics (Kim & Park, 2012); STREAM as **s**cience, **t**echnology, w**r**iting, **e**ngineering, **a**rts and **m**athematics (Root-Bernstein & Root-Bernstein, 2011); STEMM as **s**cience, **t**echnology, **e**ngineering, **m**athematics, **m**edicine (Miller & Kimmel, 2012) are used across literature, policy, and publications to introduce other subject areas. These alternate acronyms are not within the scope of this study.

STEM as an interdisciplinary subject is widely asserted and has been explored through various approaches (Mehalik, Doppelt, & Schuun, 2008; Tytler et al., 2008).

The term ‘STEM skills’ refers to interdisciplinary thinking, capabilities and common skills that students develop as a result of STEM teaching (Prinsley & Johnston, 2015; Rosicka, 2016). STEM skills include interdisciplinary metacognition (Tytler, Symington, & Smith, 2011) and the Australian Curriculum General Capabilities (Australian Curriculum Assessment and Reporting Authority [ACARA] 2017) that students and teachers use when learning and teaching in an interdisciplinary STEM task (e.g. Cartledge, 2010; Education Council Secretariat, 2015; Sanders, 2008; Satchwell & Loepp, 2002). The literature suggests there is an increasing focus on students’ and graduates’ abilities to demonstrate problem-solving skills, life-long learning abilities and abilities to adapt to challenges. Researchers have argued that these skills should be developed through STEM learning experiences (Marginson et al., 2013; Prinsley & Johnston, 2015; Rosicka, 2016).

With multiple configurations of STEM teaching, a detailed exploration of the ways of knowing and understanding is required to effectively investigate teachers’ praxis when planning and assessing interdisciplinary STEM learning experiences. Having outlined the terminology, in STEM and STEM skills literature, as a complex area this review introduces the technological, pedagogical and content knowledge (TPACK) framework (Mishra & Koehler, 2006, 2008) as a tool for understanding teachers’ knowledge.

The TPACK framework

The technological, pedagogical and content knowledge (TPACK) framework (Mishra & Koehler, 2006, 2008) (Figure 1) prompts teachers to evaluate the relationships between the content they teach, the pedagogies they use and the technology they integrate, and its seven knowledges[2] provide a flexible framework for examining a wide range of contexts, including STEM (Mehta, Mehta, Berzina-Pitcher, Seals, & Mishra, 2016; Mishra & Koehler, 2008).

The TPACK framework is not without tensions in the literature. While there is general consensus about the value of the TPACK framework across educational technology research literature, it has been argued that there is little development of the framework as a theoretical model (Graham, 2011). Varying definitions of the different knowledge types and the boundaries between these can also lead to confusion in the research literature (Graham, 2011), one such tension is found in conflicting views between TPACK as primary knowledge types that contribute to the 'TPACK' as integrative knowledge, and the view that the TPACK intersection is a new form of knowledge; a transformative knowledge (Graham, 2011).

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[2] The intersection of three primary knowledge types, content knowledge (CK), pedagogical knowledge (PK), and technological knowledge (TK), form the TPACK (Mishra & Koehler, 2006, 2008). Additionally, there are intersections between each of these forms of knowledge: pedagogy and content (PCK); technology and content (TCK); and technology and pedagogy (TPK) (Mishra & Koehler, 2006, 2008). These are considered in different contexts (Mishra & Koehler, 2008).

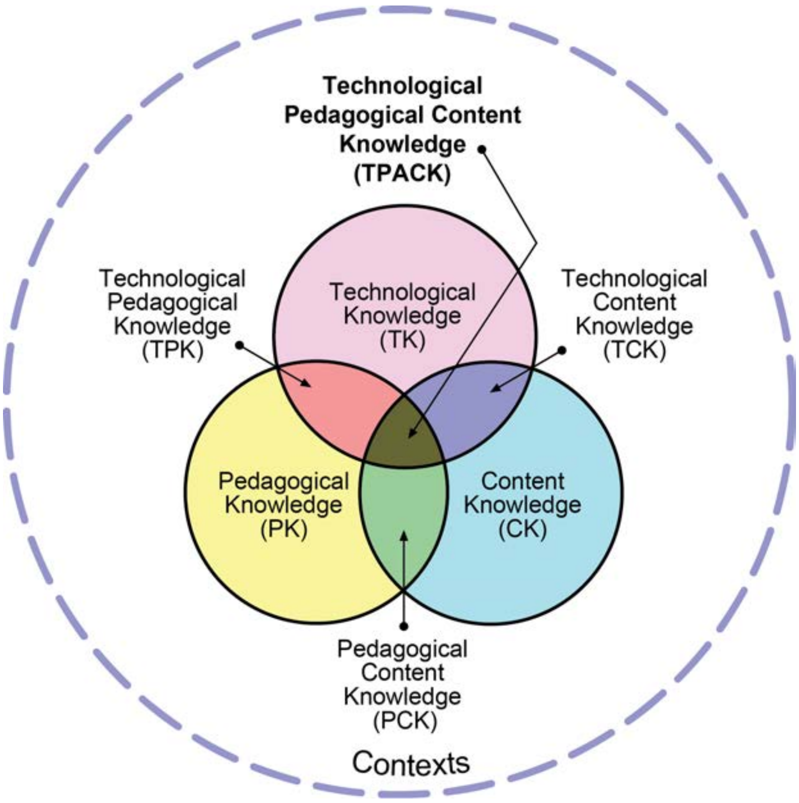

Figure 1 TPACK Framework (Mishra & Koehler, 2006, 2008)

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STEM and the TPACK framework

In a STEM context the TPACK framework provides a theoretical lens for analysing the knowledge that teachers draw upon when designing STEM learning experiences for students (Mehta et al., 2016; Mishra & Koehler, 2008). The combined domains of the TPACK framework are important for STEM teachers because effective STEM teaching incorporates pedagogy, technology, content knowledge, and combinations of each (Hudson, English, Dawes, King, & Baker, 2015; Hunter, 2017; Mishra & Koehler, 2006, 2008; Rosicka, 2016).

Early studies linking the TPACK framework to a STEM context begin in pedagogical knowledge (PK), and pedagogical content knowledge (PCK) studies of

STEM contexts, such as those found in Rosicka (2016) (e.g. English, Hudson, & Dawes, 2013). However, the first application of TPACK to a STEM context was presented by Mishra and Koehler (2006, 2008) in Mishra et al. (2016). This study identified TPACK as knowledges that educators use when planning and implementing interdisciplinary STEM lessons, and set a precedent for exploring how teachers draw on TPACK in STEM (Mehta et al., 2016; Mishra et al., 2016).

In the literature linking STEM and TPACK Mehta et al. (2016) identify several key themes that demonstrate how the TPACK framework supports teachers to design effective STEM tasks, such as combining real-world scenarios that connect with students' lives, hands-on project-based activities and the use of technology, which result in teachers planning engaging STEM learning experiences for their students (Mehta et al., 2016). In connecting with students' lives, teachers plan interdisciplinary lessons that draw on students' problem-solving and metacognitive skills, consider student diversity and interest, connect abstract ideas to hands-on applied learning, and draw together TPACK in the planning and design of lessons (Mehta et al., 2016).

While the TPACK framework provides a helpful theoretical lens with which to view teachers' knowledge, it does not prescribe pedagogical practices across learning areas and subject disciplines. For this reason, the next section examines pedagogic approaches relevant to STEM education.

STEM pedagogical knowledge

STEM education research clearly points to effective pedagogical approaches that are part of an epistemological shift away from transmissionist teaching toward constructivist pedagogy[3] (Kelley & Knowles, 2016; Ramírez-Montoya, 2017; Rosicka, 2016). Within a context that recognises the importance of constructivist pedagogy, teachers are often expected to develop comprehensive subject-specific pedagogical knowledge to design STEM learning. Each discipline has a unique range of suggested pedagogical approaches. Science is often taught through the 5Es instructional model (Rosicka, 2016) or the Science Inquiry Skills within the Australian Curriculum (ACARA 2017; Rosicka, 2016). Digital technologies and design and technologies are often taught through a "*systematic approach to experimentation, problem-solving, prototyping and evaluation*" suggested in the Australian Curriculum (ACARA, 2016). In mathematics, while there is no explicit pedagogy. Understanding, fluency, problem-solving, and reasoning are the main proficiencies teachers must consider in their planning (ACARA, 2017). Suggestions by the Education Council Secretariat (2015) indicate an initial focus on project-based learning (PBL) strategies to support an integrated STEM pedagogic approach, this important form of pedagogic and content (PCK) knowledge and praxis is explored below.

It has been extensively argued that STEM provides an opportunity to connect disciplines rooted in traditional epistemic pedagogic approaches and to embrace an interdisciplinary approach (Rosicka, 2016; Tytler, Appelbaum, & Swanson, 2015; Tytler et al., 2011), which also provides an opportunity to move toward constructivist

[3] In the former approach, knowledge and understanding is transferred from expert to learner with the view that the learner has little or no understanding of the concept, or prior learning. Through constructivist pedagogy the learner assembles knowledge socially, often with the guidance of an expert (Ramírez-Montoya, 2017). STEM policy and literature increasingly calls for a focus on student-centred, problem-based, and real-world teaching through a constructivist pedagogy (Chapman & Vivian, 2017; Kelley & Knowles, 2016; Tytler et al., 2011).

and student-led pedagogies (Marginson et al., 2013), for example the project-based learning approach suggested by Education Council Secretariat (2015); different ways of doing (National Research Council, 2009); and experiencing, conceptualising, analysing, and applying (Kalantzis & Cope, 2008; Rosicka, 2016).

Opinions on STEM teaching approaches are varied. The Education Council Secretariat (2015) suggest *“delivering project-based learning for STEM”* (p. 8), adding that there should be an increased focus on “*real world approaches to science education*” (p. 8). Chapman and Vivian (2017) suggest “*relevant and quality resources, based on real world problems that develop in-demand STEM skills aligned with the Australian Curriculum*.” (p. 53). These approaches should not be adopted without consideration of the effects on students’ learning, and teachers’ assessment practices. Kalantzis and Cope (2008) suggest that traditional assessment strategies are often used in conjunction with such approaches, and that leaving these approaches in place, such as rewards-based systems, creates a learning and assessment disjunct.

Having explored the variety of pedagogic knowledge teachers need to develop, the next section introduces the content knowledge teachers draw on in planning interdisciplinary STEM learning experiences. This exploration links with the Australian Curriculum (ACARA 2017), among other content knowledge, as preliminarily explored above.

STEM content knowledge

This section investigates how teachers draw on their knowledge of two or more STEM learning areas to design STEM learning experiences for students (Sanders, 2008), requiring teachers to have a strong content knowledge to help students develop

STEM conceptual understandings and skills. Teachers' content knowledge is an important consideration in relation to the value teachers place on content in assessment. As there is no consensus about STEM definitions, educators face design decision tensions about the place of curriculum in their lesson design.

There are two dominant curriculum planning content models in STEM apparent in the literature. In both, a STEM subject is not seen as a replacement for the learning areas it may integrate (Johnson, 2013; Stohlmann, Moore, & Roehrig, 2012); however, it combines at least two of the STEM learning areas, and often General Capabilities. The first of these curriculum content models is the teaching of STEM within a science or technology lesson, typically focussing on the primary learning area within that subject (Hunter, 2017; Marginson et al., 2013). The second model is the teaching of STEM as an independent subject or series of learning tasks that incorporate content and concepts from disciplines within STEM (Hunter, 2017; Tytler et al., 2011). Both approaches also allow for teachers' integration of General Capabilities, or practical skills (Johnson, 2013; Stohlmann et al., 2012). For those teachers undertaking STEM as an additional subject while maintaining science, technology and mathematics as discrete areas, there is agreement that the disciplinary content knowledge for each of these domains is significant, though may not be easily combined (Education Council Secretariat, 2015; National Research Council, 2009). Ultimately, for both approaches, regardless of combination or stand-alone, the teaching of STEM requires teacher confidence in their knowledge of specific discipline curriculum, while they also find new and authentic ways of teaching STEM (Johnson, 2013).

An additional consideration, regardless of content approach, for teachers' content knowledge in STEM is the General Capabilities (ACARA Australian

Curriculum Assessment and Reporting Authority, 2017; 2016). These inform students' development of STEM skills and interdisciplinary metacognition, which is a skill that enables students to draw on past experience, then analyse and solve problems and apply disciplinary concepts across STEM learning areas (Kalantzis & Cope, 2008; Mehta et al., 2016). Students' interdisciplinary metacognition is developed as a result of teachers' planning and teaching of STEM subjects (Becker & Park, 2011; Blackley & Howell, 2015; English & King, 2015; Hudson et al., 2015) through teachers employment of problem-solving and emphasising development of cognitive skills (Becker & Park, 2011; Mehta et al., 2016; Rosicka, 2016) through the General Capabilities (ACARA 2017; Rosicka, 2016). As a critical content consideration, the General Capabilities are, broadly, literacy, numeracy, information and communication technology, critical and creative thinking, personal and social capabilities, ethical understanding, and intercultural understanding (ACARA, 2017).

In linking content and pedagogy (PCK), literature suggests that project-based learning may provide additional opportunities for students to develop STEM skills and interdisciplinary metacognition (Brears, MacIntyre, & O'Sullivan, 2011; Pryor & Kang, 2013). A further review of project-based learning literature is conducted below in relation to the pedagogic and content knowledge teachers must possess to design effective STEM learning experiences. Emphasised in the preceding section is the importance of, and tensions in, teachers' STEM content knowledge, a critical part of their planning of interdisciplinary STEM learning experiences. Having elaborated on pedagogic knowledge and content knowledge, the literature related to the technological knowledge area of TPACK is explored below.

STEM technological knowledge

Technological knowledge is foundational in the teaching of STEM (Akgun, 2013), and the TPACK framework (Mishra & Koehler, 2006, 2008). Teachers' technological knowledge is a valuable consideration in the design of STEM learning experiences for students as many of the discipline pedagogic and content approaches explored make use of information and communication technology (ICT). Likewise, technological knowledge (TK) is a foundational knowledge to consider in addressing teachers' planning of interdisciplinary STEM learning experiences and teachers' assessment of STEM learning, explored below.

As discussed, the General Capabilities are an important element in students' development of STEM skills and interdisciplinary metacognition. One General Capability is the ICT capability. Teachers' knowledge of ICT as a tool to facilitate students' learning is critical in STEM teaching. Ge, Ifenthaler, and Spector (2015) establish the importance of exploring teachers' technological knowledge when they note that students require support to be capable and literate in ICT, especially when constructing and communicating information in order to solve complex STEM problems (Akgun, 2013; Ramírez-Montoya, 2017). Effective ICT integration enables teachers to identify tools for students to develop their conceptual knowledge, collect data, analyse data, make connections between concepts, access safe experimental procedures, and communicate and share learning (ACARA 2017). These possibilities are emphasised in findings from Mehta et al. (2016) who indicate that ICT is integrated by teachers to support experimentation and facilitate deep learning. This study adopts the view that teachers should understand the potential uses of ICT for learning (Mishra & Koehler, 2008).

It is critical to consider teachers' deep knowledge of ICT and TK in their STEM teaching, as the design and technologies, digital technologies, and ICT General Capability (ACARA 2017) each require a strong foundational knowledge of technology and content (TCK) (Mishra & Koehler, 2006, 2008). This knowledge type joins PK and CK as keys to understanding teachers' knowledge.

The TPACK framework in a STEM context, as explored above, provides key insights into the research questions which guide this study. The review of literature surrounding frameworks in a STEM context also raises questions about teachers' approaches to STEM teaching and the value they place on conceptual understanding and skills. To explore these questions this literature review introduces the gold standard project-based learning (PBL) (Larmer et al., 2015) framework and the Learning by Design (Kalantzis & Cope, 2008) model, below.

Gold standard project-based learning

As described above, each discipline has a unique range of suggested pedagogical approaches. The Education Council Secretariat (2015) indicate, however, an initial focus on project-based learning (PBL) strategies to support an integrated STEM pedagogic approach. PBL is described below, then the Gold Standard PBL model is introduced as a framework to understand teachers' practice in relation to teachers planning of interdisciplinary STEM learning experiences for primary school students.

PBL is a teaching approach that calls on experience and reflection for developing students' understanding (Dewey, 1963; Larmer et al., 2015). PBL is different from other teaching approaches in that students work on extended projects, with the support of their teacher, to investigate, collaborate, and respond to an authentic challenge or question (Larmer et al., 2015). Teachers require an understanding of each knowledge area of the TPACK to plan and implement PBL lessons. Literature suggests that primary school STEM teachers adopt a PBL approach which will contribute towards achievement of the 'national collaborative actions' (Education Council Secretariat, 2015) for STEM teaching (Capraro & Slough, 2017).

PBL literature has developed recently to respond to a call for a rigorous set of standards (Larmer et al., 2015). This response arose from the need to inspire students' motivation to participate in projects, questions about the educational value of certain kinds of projects, and a potential lack of educational purpose in even the most complex projects (Burlbaw, Ortwein, & Williams, 2017). Many of these tensions have been addressed through development of Kilpatrick (1918) PBL, eventuating in a rigorous set of standards (Blumenfeld et al., 1991; Larmer et al., 2015) and ultimately culminating in the development of the gold standard project-based learning model (Larmer et al., 2015).

The gold standard PBL model begins with teachers creating a design brief; a set of specifications for a desirable end product (Larmer et al., 2015). Students then construct, or are provided with, a procedure to reach their end goal. Students learn through explicit instruction when they encounter a barrier they are unable to overcome on their own. This is labelled a 'teachable moment' (Larmer et al., 2015). Next, teachers guide or coach students, providing or helping them find the knowledge needed to pass the barrier. Throughout the process students reflect on the learning they are undertaking; this may be a formal or informal process. Students seek feedback and revise their work and they often create many drafts before presenting a final product to an authentic audience (Larmer et al., 2015).

PBL is the main approach to STEM suggested in policy and in research publications (e.g. Burlbaw et al., 2017; Capraro & Slough, 2017; Education Council Secretariat, 2015; Pryor & Kang, 2013). PBL also addresses many of the key STEM education policy goals: integrated, real-world, authentic, and project-based learning. Capraro and Slough (2017) provide a useful, although predominantly secondary school-focussed, definition:

> *We define STEM PBL as an ill-defined task within a well-defined outcome situated with a contextually rich task requiring students to solve several problems which, when considered in their entirety, showcase student mastery of several concepts of various STEM subjects* (p. 2).

Capraro and Slough (2017) suggest that the essential project design elements (Figure 2) and the practices of PBL can be addressed and tailored to meet a STEM PBL (Capraro & Slough, 2017; Larmer et al., 2015). In addition to tailoring the gold standard PBL to a STEM context, these project design and teaching practice elements may be linked as a whole to critical knowledges (TPACK) for teachers' to consider and draw on when teaching STEM.

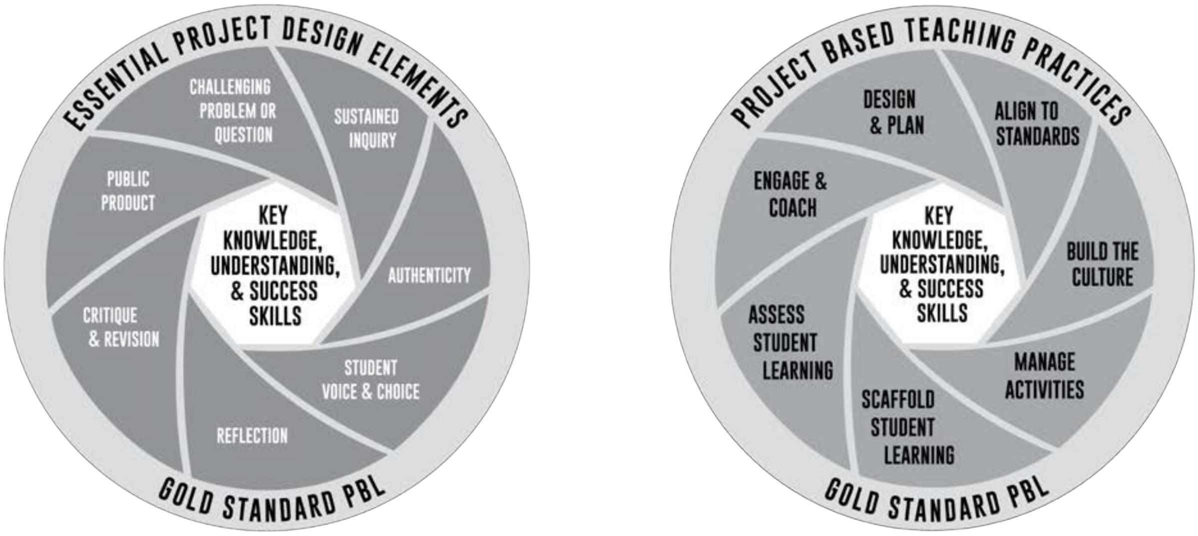

Figure 2 Essential project design and teaching practice elements in 'Gold Standard' PBL (Larmer et al., 2015)

PBL is a teaching approach recently adopted in STEM education at a primary, secondary and tertiary level. However, limited literature suggests that this area is still being researched and that there are no definitive strategies for the teaching of STEM through PBL (Burlbaw et al., 2017; Capraro & Slough, 2017; Pryor & Kang, 2013). Importantly, this study has been deliberately designed to investigate this silence, providing new information about PBL in a STEM context in Australia through exploration of teachers' STEM planning and assessment. The following section explores one alternative approach to PBL which is problem-based learning[4].

[4] NB: this is an alternative approach to STEM teaching, not an alternative model for understanding teachers' STEM practice.

Problem-based learning shares several of the key attributes of project-based learning[5]. Problem-based learning deviates from PBL in that rather than many ‘problems’ toward one final product, problem-based learning asks students to find a solution to a single multifaceted problem (A. E. Walker et al., 2015). Problem-based learning, like PBL, uses open-ended tasks, is typically focussed on long-running projects, emphasises inquiry and student self-direction, and requires the application of skills in appropriate ways (Larmer, 2014). Problem-based learning, as implied in the name, requires a carefully selected problem that students will focus on. This problem is often multifaceted and interdisciplinary in nature (A. E. Walker et al., 2015).

The acronyms for project-based and problem-based learning, both PBL, can be confused. Given that both are teaching approaches, and the two terms are *not* synonymous, it is important to consider how teachers may respond to policy demands for a PBL approach (Capraro & Slough, 2017). Beyond policy documents that refer to problem-based learning and project-based learning there is little to suggest which of these, or other teaching strategies, are being used in primary school classrooms, which is a key question for this study.

PBL approaches are acknowledged for adding value in the teaching of STEM; indeed, there is a suggestion that PBL and problem-based learning cannot be

[5] Both project-based learning and problem-based learning fall under the ‘inquiry learning’ or xBL group of learning theories (Thomas, 2000; A. Walker & Leary, 2009). These theories are based on the work of Dewey (1963); Dewey and Small (1987) who position inquiry, project-based, and problem-based learning as student-centred, active learning approaches that include critical thinking and problem solving (A. E. Walker, Leary, Hmelo-Silver, & Ertmer, 2015). Project-based and problem-based learning are the focus of this review as they are the two approaches most prevalent in STEM literature (Burlbaw et al., 2017; Capraro & Slough, 2017).

separate from STEM in a truly interdisciplinary curriculum (Chapman & Vivian, 2017; Education Council Secretariat, 2015). To support the first research question, this literature review has expanded on gold standard PBL as an important model for understanding teachers' knowledge (TPACK) and practice when designing interdisciplinary STEM learning experiences for students, and has introduced problem-based learning as an alternative approach. In the next section the Learning by Design (Kalantzis & Cope, 2008) model is introduced as a lens to understand how teachers' value and evidence of students' development of STEM content knowledge and skills.

Learning by design model

The Learning by Design model, created by Kalantzis and Cope (2008), provides four quadrants that explore students' development of knowledge and skills when drawing together their PCK related to discipline knowledge, pedagogical knowledge related to project and problem based learning. This model is useful in a STEM context to help teachers plan learning and understand students' past experiences by addressing different ways of knowing for students (Kalantzis & Cope, 2008). It details an effective pedagogic process that teachers can use, through different ways of knowing, ways of learning, and sites of learning through four quadrants (Figure 3) (Kalantzis & Cope, 2008). This section explores how the Learning by Design model supports teachers to design meaningful STEM learning experiences, valuing students' conceptual knowledge and skill development, and building on their own pedagogical and content knowledge (PCK), while also responding to the Australian Curriculum, using a PBL approach.

The quadrants of this model illustrate what the literature suggests are effective learning outcomes for students resulting from teachers' pedagogical approaches (Mishra & Koehler, 2006, 2008). For example, the initial 'experiencing' quadrant links to the importance of discovery and wonder when students engage in STEM learning (Mehta et al., 2016); the 'conceptualising' quadrant relates to the importance of making connections between students' past learning experiences and new learning (Kalantzis & Cope, 2008; Mehta et al., 2016); and the 'analysing', and 'applying' quadrants relate to STEM skills and the metacognitive processes of applying discipline-specific concepts in a broader context, such as to a product (Lehrer, 2009).

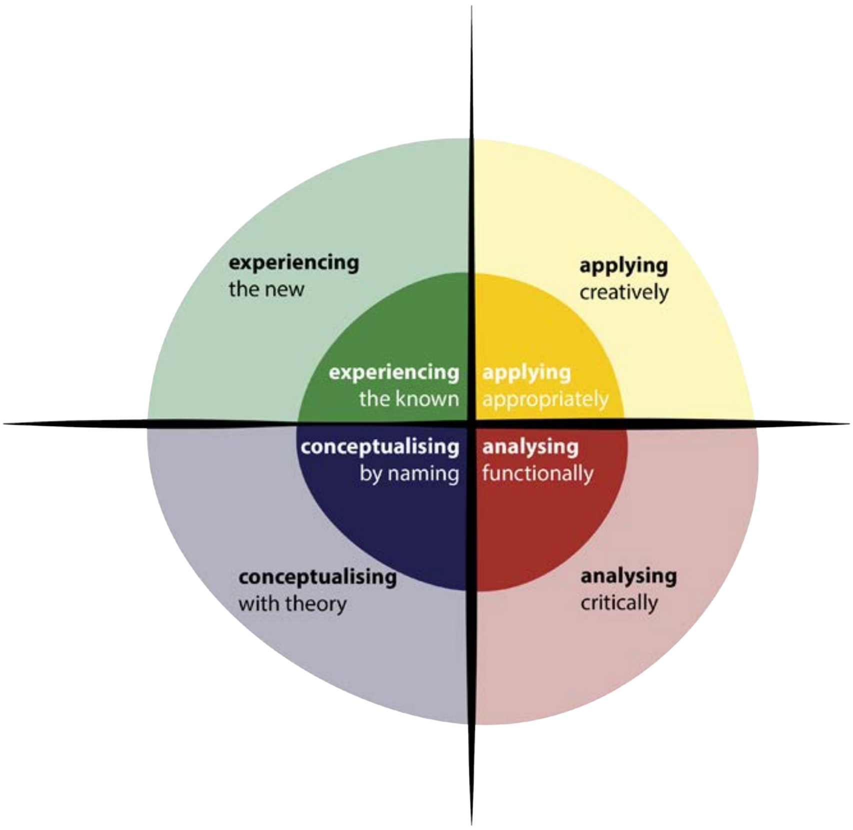

Figure 3 Learning by Design Model (Kalantzis & Cope, 2008)

The Kalantzis and Cope (2008) model provides teachers engaged in STEM teaching with a theoretical lens with which to examine how traditionally discrete subjects may come together, both pedagogically and through skills, content and concepts of the disciplines. The model was explicitly designed to promote deep knowledge connections and emphasise the creation of meaning in students' development of knowledge (Kalantzis & Cope, 2008). In STEM education the facilitation of deep knowledge connections have been explored through real-world problem solving, focussed on connecting students' conceptual understandings to learning tasks (Becker & Park, 2011; Blackley & Howell, 2015; English & King, 2015).

Exploration of the processes that teachers may use to support application of conceptual knowledge and stimulate students' development of STEM skills and interdisciplinary metacognition is needed. To address this gap, this study will investigate how teachers' collection of evidence for assessment of students' understandings may be aligned to the Learning by Design model. This model provides opportunities to identify what teachers value as *evidence to evaluate their impact on students' learning* as it provides insight into the development of students' conceptual knowledge and skills. This exploration will illuminate how teachers' practice impacts on students' development of STEM conceptual knowledge and skills (Kalantzis & Cope, 2008; Lehrer, 2009; Tytler et al., 2015).

This section has detailed how the Learning by Design (Kalantzis & Cope, 2008) model may be used to understand the types of student knowledge and skills teachers develop in a STEM context (Mishra & Koehler, 2006, 2008). This is an important theoretical framework for this study and connects with the TPACK as a consideration for teachers' knowledge in planning and assessment, and gold standard PBL, because key knowledge, understanding and success skills are at the core of effective PBL teaching (Larmer et al., 2015). The next section explores the literature related to the assessment of students' STEM learning.

Formative assessment in STEM

With the explored literature emphasis on conceptualising STEM, there is little extant literature pertaining to STEM assessment. As noted, there is diversity in STEM curriculum, or content knowledge (CK) and need for flexibility in teachers' pedagogic knowledge (PK). This makes identifying assessment practices specific to STEM difficult. However, formative assessment practices, which have been documented in a STEM context, are elaborated below, raising important questions regarding teachers' identification of evidence of the impact of their STEM teaching on students. Rosicka (2016) states that there is a need to agree on *"methodologies and metrics to assist the assessment of impact and participation in STEM education"* (p. 6). Consideration of the options for assessment in STEM are investigated in this section.

Formative assessment provides opportunities for teachers to collect evidence of their impact on students' learning throughout the learning process, a practice emphasised in PBL (Larmer et al., 2015), and gives teachers the opportunity to evaluate students' development of conceptual knowledge and skills (Kalantzis & Cope, 2008). Notably, Black and Wiliam (1998) conducted an extensive literature review that revealed formative assessment as the most effective assessment method across all learning areas. Formative assessment is conducted through the collection of evidence and is defined in Black and Wiliam (2009) as *"evidence about student achievement [that] is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction"* (p. 7). Tytler et al. (2008) noted that the use of formative assessment develops student self-direction and encourages innovative assessment practice from teachers and students in STEM. The use of formative assessment in science and mathematics also leads to increased student engagement (Tytler et al., 2008; Wiliam, Lee, Harrison, & Black, 2004). This is significant for STEM teaching as engagement has been identified as a major goal of STEM education (Chapman & Vivian, 2017).

Existing literature relevant to the assessment of STEM learning focusses on teaching of STEM inside a science or technology lesson, typically focussing on the primary learning area within that subject[6] (Hunter, 2017; Marginson et al., 2013) rather than a series of learning tasks incorporating many key learning areas. One such example is found in Tytler et al. (2008) who conducted an extensive literature review which suggests that STEM assessment initiatives often focus on single-discipline classes (e.g. Cantrell, Pekcan, Itani, & Velasquez-Bryant, 2006; Elliott, Oty, McArthur, & Clark, 2001; Fortus, Krajcik, Dershimer, Marx, & Mamlok-Naaman, 2005; Mehalik et al., 2008). While the evidence presented by Black and Wiliam (1998) about formative assessment can be generalised across any learning area, literature specific to STEM formative assessment appears to be limited. Importantly, this study will address this limited exploration of assessment practices in STEM by examining teachers' planning of learning experiences drawn from STEM content knowledge to understand how teachers assess students' learning in STEM and what evidence they use to evaluate their impact on student learning.

[6] NB: for the most part, this literature focusses on the teaching of STEM in a secondary school context. Primary school teachers may be more focussed on teaching STEM as a series of lessons as they tend to be less discipline bound than secondary schools.

The Education Council Secretariat (2015) notes that there is a lack of STEM assessment tools and seeks national action toward STEM education that includes the development of online formative assessment tools. This lack of tools may be a result of the diversity of definitions of STEM, the variety of curriculum content models, and the different discipline-specific and general pedagogic approaches. Developing such STEM assessment tools may prove difficult because, as highlighted throughout this literature review, there is not a consensus about definitions of STEM, or agreements about effective STEM pedagogical approaches. The variety of pedagogic practices and content models require different assessment tools to assess the impact of STEM education on students in different contexts (Mishra & Koehler, 2008).

This section has emphasised the importance of formative assessment practices and the limited literature related to teachers' assessment practice and reflection on their impact on students' learning, especially in an independent subject or series of learning task models. This study will address this gap through the second research question, in conjunction with the analysis against the frameworks explored above for the first and second research question.

Chapter Conclusion

This literature review has covered two key areas within the extant STEM literature and three significant lenses for exploring teachers' STEM praxis.

The first area the review identified was the tension in terminology used in extant literature. Ambiguity in acronym choice was identified, and important considerations for interdisciplinary STEM teaching elaborated to identify the knowledge and skills teachers must develop in students.

The first lens, the TPACK framework, provides this study with the opportunity to explore teachers' knowledge in relation to their planning of interdisciplinary STEM learning experiences. In addition, the framework provides the opportunity to expand on the context in which the teacher participants operate. The TPACK framework enabled investigation of different STEM pedagogies, content, and technology. The STEM PK section highlighted an epistemological shift away from transmissionist teaching, toward constructivist pedagogy, emphasising PBL as a constructivist and student-led pedagogy. The STEM CK section emphasised the need for teachers' development of sophisticated content knowledge to help students develop STEM conceptual understandings and skills especially in regard to teachers' planning of interdisciplinary learning experiences. Finally, the STEM TK section described the need for teachers' technological knowledge, highlighting a variety of ICT tools to support STEM learning experiences.

The second lens, the gold standard PBL model, was introduced as an extension to TPACK, to explore the knowledge and skills of teachers planning interdisciplinary STEM learning experiences. The PBL approach, in conjunction with the gold standard PBL model enables this study to explore teachers' knowledge and praxis and responds to approach suggested in policy and research publications (Burlbaw et al., 2017; Capraro & Slough, 2017; Education Council Secretariat, 2015; Pryor & Kang, 2013).

The third lens, the Learning by Design model, was introduced as a framework to understand teachers PCK in relation to their collection of evidence and evaluation of their impact on student learning. The model will be used in this study to explore participants' planning of interdisciplinary STEM learning experiences by addressing different ways of knowing for students. This study will investigate how teachers' collection of assessment evidence may be aligned with this lens.

Finally, the review explored the limited extant literature pertaining to STEM assessment and suggested formative assessment as an area to be expanded in the STEM context. The review emphasised that formative assessment practices provided teachers with opportunities to collect evidence of their impact on students' learning over time, linking formative assessment with the PBL approach and the gold standard PBL model. Through the gold standard PBL model, teachers' knowledge of assessment can be related to the TPACK framework.

Chapter 3: Research Design

This chapter details the research design for this study. It outlines the research approach taken, the methods used, including data collection and analysis, and the epistemological stance adopted to address the research questions.

As suggested in the Literature Review chapter, this is an emergent field with a growing body of research literature. Further exploration is required to understand the planning and assessment practices of teachers in STEM, signalling that a qualitative, interpretivist study is an appropriate research design (Punch, 2014; Ritchie, Lewis, Nicholls, & Ormston, 2014). To investigate this emergent area, this study investigated the classroom practice of four teachers, specifically their praxis, vis-à-vis planning and assessment of STEM learning experiences for primary school students.

Approach

A qualitative inquiry approach was adopted for the design of this study. The qualitative inquiry approach was defined by Creswell (1998) as a *"process of understanding based on distinct methodological traditions of inquiry that explore a social or human problem. The research builds a complex, holistic picture, analyzes words, reports detailed views of informants, and conducted the study in natural setting"* (p. 249). This approach makes it possible to explore teachers' STEM planning and assessment (Creswell, 1998; Lincoln & Guba, 1985), as it is appropriate for identifying and interpreting the classroom pedagogical practices, and knowledge of teachers (Burr, 2015; Creswell, 2012; Crotty, 1998). It also enabled identification of teachers' perceptions of the impact of their STEM planning and implementation on students' learning. This study utilised constructionism as its theoretical framework (Burr, 2015; Crotty, 1998; Lincoln & Guba, 1985), and used an interpretivist approach for analysis of the gathered data (Ritchie et al., 2014; Schwandt, 1998). The constructionist theoretical framework is defined by the key features of: reality that is based in human practices, and constructed through interaction; the creation of meaning that requires a mind or person; and the creation of meaning that happens in a social context (Burr, 2015; Crotty, 1998; Ritchie et al., 2014).

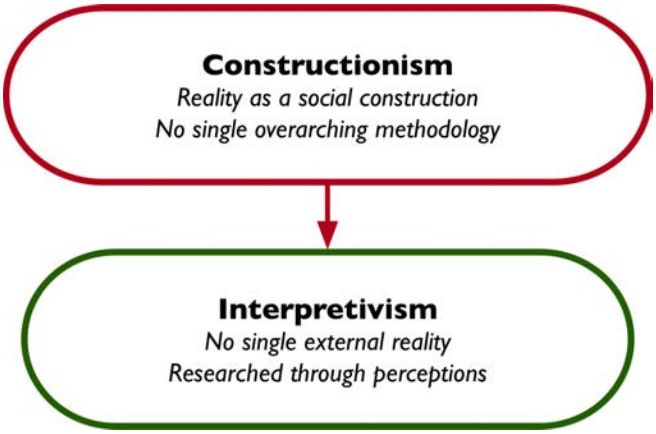

Figure 4 Epistemology & theoretical perspective (Adapted from Punch, 2014)

According to Ritchie et al. (2014) an interpretivist approach is useful because:

> *natural science methods are not appropriate for social investigation. [The researcher must] explore and understand the social world through the participants' and their own perspectives [with] explanations offered at the level of meaning rather than cause and effect* (p. 24).

Given the relatively unexplored, and emergently nuanced area, the researcher adopted an inquiry approach to investigate the knowledge and practice of teachers. There are complicated processes in teacher practice, these require appropriate application of interpretivist methods. Thus, the next section explores the interpretivist method adopted.

Methods

This section details the methods chosen for this study. First, the selection criteria for the teacher-participants is established; a critical consideration in the success of this study, particularly with regard to the vast possibilities within the study population (Punch, 2014; Ritchie et al., 2014). Next, data collection methods for two rounds of individual interviews conducted with identified teacher-participants are expanded (Creswell, 2012; Punch, 2014). Finally, methods for data analysis are unpacked, including recording and subsequent transcription, coding, and analysis against the research questions and selected frameworks. This analysis resulted in presentation of rich data (Ritchie et al., 2014) and lead to clarity in response to the questions raised in the literature review (Crotty, 1998; Merriam & Tisdell, 2015).

Selection of Participants

Participant selection was based on a set of criteria that enabled collection of rich data (Ritchie et al., 2014). Participants were chosen from a variety of backgrounds, with highly regarded, but varied, approaches to STEM. These participants were chosen using specific sampling.

This study made use of a purposeful sampling, specifically snowball sampling (Creswell, 2012; Merriam & Tisdell, 2015; Patton, 2014), to recruit a selection of highly skilled primary school STEM teachers. These teachers were identified as demonstrating both comprehensive understanding of interdisciplinary STEM planning and their ability to plan and design assessment of STEM learning tasks in a primary school setting.

A number of gatekeepers (Creswell, 2012, p. 211) were called upon by the supervisor for the project that included representatives of professional organisations, those related to the teaching of STEM, and school leaders. These gatekeepers provided the contact details of potential participants they believed would meet the criteria of the research project. The potential participants were contacted by the supervisor to ascertain their interest in voluntary participation. After discussion with potential teacher-participants, four teacher-participants were chosen for this study. They represented different geographical locations; three from urban South Australia and one from urban Victoria. These participants henceforth will be referred to as teacher-participants as a group, or by the pseudonyms Henry, Kate, Rosa, and Stephanie (alphabetical sorting).

The criteria used for the selection of each participant was:

I. An upper primary teacher of years 4, 5, 6 or 7 from an urban or inner regional Australian school who was identified through colleagues, professional associations, or known to the researcher/supervisor as an exemplary teacher or coordinator of STEM learning;

II. Willing and able to provide an annotated sample of student STEM work (a product or artefact) that they planned and assessed in the last nine months;

III. Willing and able to provide annotated planning documents that demonstrated their STEM unit planning process;

IV. Willing and able to participate in the required components of the research, two individual interviews.

Data Collection

To answer the research questions for this study the methods for data collection and analysis were established and are explored below. This study was designed to collect three sets of rich data from participants, and involved researcher-participant interaction on two occasions.

1. Semi-Structured Individual Interview

The first researcher-participant interaction was a semi-structured individual interview (Creswell, 2012; Ritchie et al., 2014), conducted with each participant. Ritchie et al. (2014) suggest that data drawn from interviews are "*based on verbal communication and spoken narratives*" and that "*individuals who actively construct their social worlds can communicate insight about [them] verbally*", elaborating that the interview remains an "*effective method of qualitative data collection*" (p. 55). The individual interviews were designed in such a way as to stimulate rich discussion (Punch, 2014), drawing from the daily practice of teachers who are planning, implementing and assessing interdisciplinary STEM learning, and evidencing student learning.

2. Annotated Classroom Artefact

Participants were asked to bring a student work sample that exemplified a students' STEM learning journey to the follow up interview. According to McDonald (2001) work samples and classroom artefacts shape the way that we come to understand the products of classroom activities. He records that students' understanding is visible in their work, notably, student work samples that anchor teachers' planning, assessment and practices to the realities of the classroom (Clare & Aschbacher, 2001; McConney, Schalock, & Schalock, 1998; Owen, 2015)

A preliminary criterion for the selection of an artefact was designed as follows:

I. It reflected work students had completed in the last nine months;
II. It highlighted the learning that has been undertaken over time by the student;
III. It was aligned with STEM learning through the Australian Curriculum (or state variants) learning areas;
IV. It was work that was de-identified by the teachers.

The teacher-participants were asked to bring a sample of students' STEM work (a 'classroom artefact') that the participants perceive as demonstrating that the students have understood the intentions of their planning. These classroom artefacts were annotated by the teachers to indicate the evidence of their planning in the STEM work samples. The teachers' annotated classroom artefacts were brought to the second of the researcher-participant interactions and shaped the discussion.

3. Semi-structured Follow-up Interview

The second participant-researcher interaction was a semi-structured interview (Creswell, 2012; Ritchie et al., 2014) with each participant drawing on the classroom artefacts to facilitate the participants' telling of a story (Merriam & Tisdell, 2015) about their teaching of interdisciplinary STEM (Rosicka, 2016), and serving as an opportunity for describing the praxis that participants had detailed in the initial interview through the anchor of a work sample. This interview also served as an opportunity to elaborate on each teachers' praxis for presentation in the findings, and asked them to detail the process they underwent with the student whose work they presented.

Trustworthiness

Qualitative research, may be measured fortrustworthiness instead of validity (Merriam & Tisdell, 2015; Ritchie et al., 2014). Merriam and Tisdell (2015) emphasise that trustworthiness is required because "no classroom teacher, for example, will want to experiment with a new way of teaching … without some confidence in its probable success." (p. 237). Moreover, they suggest that trustworthiness implies rigour in the research process, while quantitative research uses the terminology such as validity and reliability (Lincoln and Guba, 1985; Glaser and Strauss, 1967 as cited in Ritchie et al., 2014).

In this study, trustworthiness was enhanced by the use of participants own words, and by asking participants to confirm the researcher's interpretation of their practice during the second individual interview. In addition, the results endeavoured to maintain faithfulness to the original accounts of the teacher-participants (Crotty, 1998; Ritchie et al., 2014).

Ethical Considerations

Prior to contact with any participants the researcher applied for human research ethics approval from the *Flinders University Social and Behavioural Research Ethics Committee*. The project was approved (project number 7631) and the guidelines provided were followed to ensure ethical conduct. Importantly, each teacher-participant was provided an information sheet and a consent form. The consent form was returned prior to commencement of the data collection. The interviews took no more than one hour, and were semi-structured. Participants were provided with a short interview guide and the requirements for the documents for the interview. This guide is provided in the appendix to this thesis. Furthermore, each element of fieldwork was carried out without significant interruptions or other issues that may have affected the quality of the data collected (Ritchie et al., 2014).

Data Analysis & Representation

The collected data included student work samples and audio recordings of each interview. Detailed transcription of recordings was completed by the researcher (Creswell, 2012) using the NVivo qualitative data analysis software (QSR International Pty Ltd., 2014) to analyse the interviews.

Data were analysed through a pragmatic process of analytic induction, described by Ritchie et al. (2014) as a way of accessing the character of a phenomena, and through thematic analysis "*discovering, interpreting and reporting patterns of meaning within the data*" (Ritchie et al., 2014, p. 271).

This research followed practices aligned with the six steps process of analyzing and interpreting qualitative data, provided by Creswell (2012, p. 261), outlined below:

Prepare and Organize the Data for Analysis	The primary source of data was audio recordings of the individual interviews, as described. All interview recordings were transcribed by the researcher.
Explore and Code the Data	The researcher established an audit trail that followed the coding of data and the decisions made (Punch, 2014). Data were analysed through assignment of codes to interview transcript content. These codes were maintained in NVivo (QSR International Pty Ltd., 2014).
Coding to Build Description and Themes	The codes were analysed through relationships between codes to identify similarities or themes in the data. These relationships were then refined and reduced to form themes (Miles & Huberman, 1994).
Represent and Report Findings	Data were reported against defined themes in the form of rich description (Punch, 2014), and presented as cases, one case for each teacher-participant, and organised in sections addressing the two research questions.
Interpret the Findings	The presented cases were reviewed in relation to the extant literature, and relevance to the research questions (Miles & Huberman, 1994; Ritchie et al., 2014). Furthermore, the frameworks of TPACK (Mishra & Koehler, 2006, 2008), gold standard PBL (Larmer et al., 2015) and Learning by Design (Kalantzis & Cope, 2008) were used as frameworks against which to interpret the findings.
Validate the Accuracy of the Findings	To address validity and accuracy, the evidence was drawn from multiple participants and compared against extant STEM literature. In addition, findings of the first interview were discussed with the teacher-participants during the second individual interview to ensure appropriate interpretation. The presentation of results endeavoured to maintain faithfulness and dependability to the original accounts of the teacher-participants (Crotty, 1998).

Table 1 Data analysis against the six steps process of analyzing and interpreting qualitative data (Creswell, 2012)

The described method is a descriptive–interpretive analysis, informed by the qualitative methodology and commonplace in interpretivist qualitative research, which pragmatically combines elements of case representation and analytic induction (Bryman & Burgess, 1994; Ritchie et al., 2014).

Limitations of the study

This research drew on the practices of four teacher-participants who were each identified as exemplary practitioners of STEM teaching. Though the context for each of these four teacher-participants varies there are several commonalities between them, detailed in the Results chapter. Generalisations cannot be made about the teaching profession from the sample size. Furthermore, this sample is not considered representative, having been selected for high quality STEM teaching, not generalist approaches.

This chapter has introduced the methodology and methods that guided this study, positioning this study as a qualitative-interpretive study employing individual interviews as the main method for data collection. The next section introduces the results from each teacher-participant as a report, as noted in the six steps illustrated in Table 1, and initially explores how the interview data answered the guiding research questions.

Chapter 4: Results

The previous chapter outlined the methods used to generate data for this study. The Results chapter brings the findings together divided into four main sections, one for each teacher-participant:

1. Their background, detailing the context within which they work;
2. Their definition of STEM beyond the expanded acronym;
3. Their remarks about the planning process they undertake, in particular, the relationship with the knowledge the teacher-participants draw on planning interdisciplinary STEM learning experiences;
4. Finally, their assessment process, in particular, the relationship with the teacher-participant’s assessment and the evidence they use to evaluate their impact on student learning.

Teacher-participant 1: Henry

Background and context. Henry works in a high socio-economic public school in south-eastern Adelaide. He teaches STEM as a specialist subject to year 2 and year 7 classes.

Henry finds STEM teaching unique and suggested that his STEM specialist role is that of facilitator of project-based learning. He described flexibility in his teaching strategies while aiming to develop students' higher order thinking. He notes a particular difference between his STEM teaching, and other teaching:

> *I try to make it a little more free, and hand a lot more responsibility to the kids in terms of how they go about things. And giving them more room to problem solve in a less rigid structure, that is quite different.*

Definition of STEM. Henry's definition of STEM incorporated the skills from each discipline in conjunction with General Capabilities. His approach tended toward more practical and hands-on STEM learning for students. He stated:

> *It's taking the content and skills from science, technology and mathematics, bringing them together, integrating them toward the practical approach of engineering; that engineering and problem-solving process.*

Notably, Henry asserted that process skills and content knowledge shared equal significance in his epistemological stance toward STEM teaching.

Planning process. Noting that his planning often started with a stimulus, Henry explained one of the activities his year 7 classes had been focussing on, and which had generated student excitement. In the first interview he gave the example of the school's 3D printers as a stimulus. He started this unit with a series of scaffolds and pro-formas to help his students understand the possibilities of the project. By beginning with prompts and scaffolds he found it easier to link what he had planned for students into the ongoing assessment. His comment below illustrated this:

> *They have the criteria to begin with, and so we can always go for, when they say, 'This is my idea', I can say, 'Well, how does that meet with the criteria?"*

Henry drew from content knowledge in the Australian Curriculum, bringing in areas that fit well with the project he had in mind. He suggested that a majority of his focus was with the Critical and Creative Thinking capability. He noted this, stating he used "*Critical Creative Thinking, [and] problem solving, in a big way, asking sort of tough questions, and occasionally spending time just breaking down big ideas with lots of global thought about the implications.*"

In his planning Henry combined the General Capabilities with elements of the Design and Technologies learning area, noting that, as a specialist teacher, it could be difficult to find the time to teach all the conceptual knowledge that his students needed to draw on. While he had run explicit teaching workshops on concepts, he suggested it may be better if he could have worked with classroom teachers to align the specialist classroom curriculum with that of the regular classroom.

In keeping with his PBL approach, Henry noted the processes he used for scaffolding and structuring students' conceptual understandings, highlighting one struggle where, sometimes, his expectations of students' understandings fell short. He explained that when he did encounter a knowledge gap:

> *Generally, it does mean modifying at my end to fit with them. For some things we can stop and discuss it. We can stop and talk about some sort*

of fundamental concept … and I could bring everyone up to speed … but for other things, [concepts], if there is a fundamental misunderstanding of something, or they just have no experience in it, then I change my plan and go back a step.

Henry drew attention to one key aspect of his planning of STEM projects, building in conceptual understandings with students, which had developed as a result of teaching this unit over time. He emphasised:

I think they need to know, definitely, about working on skills development and really, a few different points to pause and look at the explicit teaching.

Assessment process. Henry suggested that he was able to make comprehensive assessments of students' work through the use of scaffolds and students' reflections. He conducted a variety of formative assessments, using strategies like exit tickets and interviews to make sure he knew where students were up to in each lesson. The comment below illustrates that student focus on the process was critical in his classroom:

Most of what I try to do is gear towards a final product but have evidence of process. So, the biggest thing – I talk to the kids all the time about this – I need to see their process, above all things. You know, they can have a final product, but, you know, if they don't show adequate thinking throughout the process then it doesn't mean they're going to get good marks.

Henry highlighted the struggles of moving students away from result-oriented, summative task assessments in their regular classrooms towards his assessment of process. This process had taken some time to take effect in his classroom but he was beginning to see change:

> *[The kids] don't really care how they get there, but they do care about what they get in terms of grade. So, you say, 'We should do [assess] process because it's the way we should do things,' [and they don't respond] … If you say, 'If you don't show process, the best possible mark you can get is a C', the kids immediately perk up … It's just a school culture and it does change things.*

Some students were afraid to engage with the learning due to being failure-averse. Henry suggested that this was a hurdle he faced with some students when attempting to engage them.

> *Failure is definitely something that these kids in particular struggle with, really badly actually. If they can't get immediate success in something, for most of these kids, they tend to lose interest.*

Henry stated that in his role he managed to assess students' communication and collaboration because he worked alongside them in their learning journey. He extended this role to include assessment of students through discussion and checking off incremental progress after each lesson. He stated:

> *I, informally, use a fair bit of anecdotal evidence … I've actually talked to them. They've had a bit of a conceptual breakthrough and note it down, and stuff, to account.*

Teacher-participant 2: Kate

Background and context. Kate teaches in a high socio-economic school in eastern Adelaide. She is classified as an early career teacher, having won a contract at her school after relief teaching for two years. She teaches a composite year 5-6 class. Kate's STEM teaching journey began more by coincidence than intention. She notes that, while a partnership focus on STEM has drawn her attention to the way she teaches STEM, it has been an integral part of her practice since she started teaching.

Definition of STEM. Kate focussed on STEM projects that provide hands-on learning opportunities to her students. She emphasised STEM as enabling students to learn skills through doing. She clarified that, while the hands-on approach was an important part of STEM, students' knowledge and understanding of the science, technology, engineering, and mathematics concepts were of equal importance. She outlined:

> *Even our wind-powered vehicles, we started thinking about collecting wind and what that means and the science behind it … There's learning through what we're 'doing' as opposed to all explicit teaching.*

Kate suggested a view of STEM that aligns with a reflexive style of teaching, noting that much of the learning that her students do came as a result of teachable moments; times when things they were doing required a scaffold or structure.

Planning process. Kate described her approach to STEM planning as an integrated and project-based learning approach. Kate had her students participate in different projects in a school week and she spoke about how some of the projects aligned with STEM, illustrating that:

The planning part on the program I put up for the kids, it might have a Maths lesson… or an English lesson… but it was all focussed on the one [overarching] topic. That's something I'm now thinking I'll try and take into other things [learning areas vis-à-vis projects]

In both interviews Kate highlighted student engagement in the learning by providing scenarios and context for their projects. Some of her examples included needing to defend the school garden from crows, and finding alternatives to petrol to power vehicles. She used these scenarios to link to curriculum, but she did not strictly plan all learning her students would undertake in advance. She described her approach to planning as a post-planning approach:

So, every two to three weeks, you sit down and think, 'What have we done? How does it link with the curriculum? What evidence do I have that they know this stuff?'

Kate valued content and skill development in her classroom, while equally focussing on students' interpersonal skills and the General Capabilities. She highlighted her use of the Kagan (1994) Cooperative Learning approach in her design of STEM projects. She noted her use of Cooperative learning in a STEM task:

When they were defining, they had to give their definition to a partner; their partner [gives] one to them; [then] they talk about it in their teams.

She highlighted how this process of sharing the learning also encouraged students to *"draw from each other's ideas."* Kate's unique approach developed reciprocal conversation between students supporting ideation, accountability, and stretching students to think in new and creative ways. She noted that the conversations students had with each other often produced ideas beyond what they might provide to her as the teacher, and that:

You get more creativity out of them with the process and adding in Cooperative Learning. Just the ideas they come up with; some of them are really surprising me.

Kate also offered that processes she used with students for the development of products could be helpful across different key learning areas and throughout their school life, suggesting:

> *The deliver stage, … that's all the making and building part, and then the last stage is to debrief. We go back and review the design. 'What can we do better? How can we take this further?' How they feel about the thing… So we've found those words and we're starting to use it as a whole-school approach.*

Kate emphasised ways that she had supported her students to develop understandings of STEM content. She detailed an approach that helped students become aware of the knowledge they were developing, and to assist her in the assessment of students against the achievement standards.

Assessment process. Kate reported that visibility of thinking helped students improve their knowledge over time and, through collaboration with other students, they were able to identify concepts with which they may have had a weakness. She noted that linking this shared development of understanding with assessment was a successful strategy in her classroom.

Kate described a number of strategies for the assessment of STEM learning, including formative assessment, as critical. She observed that students were required to develop knowledge and understanding along the way before committing to a final product. She developed strategies for assessment that enabled students to demonstrate understandings in an uninhibited manner. One example she provided was through the use of the digital tool *Seesaw*:

> *The Maths is a bit of a tricky one… I've had them physically show me some of the Maths, or do a Seesaw video talking about it. I know if they can explain it to me then they understand it and, quite often I say, 'Take your Chromebook and go record a video,' … I'm still getting that evidence of learning.*

Kate explained that summative assessments were also employed in her classroom. She believed that, while the formative assessments held more value during the process, students found it useful to evaluate their final product and were provided the opportunity to revise on many occasions. She detailed an assessment of a finished product using teacher, peer and self-assessment strategies:

> *They switched. They told each other about their vehicles then their peer did an assessment of it, and then they left it on the tables over the weekend. I came in and did the teacher assessment of it… They'd had to, with their shoulder partners, talk about the feedback they'd received from me. 'What had they learned from that feedback? What did they read it as?' So, before they started [again], they could take on that feedback and improve.*

Teacher-participant 3: Rosa

Background and context. Rosa teaches in a low socioeconomic public school in northern Melbourne. She teaches a composite year 5-6 class in a team-teaching environment with three other full-time teachers. Rosa’s students have recently concluded a term-long STEM project-based learning unit. Students only left the project for explicit mathematics blocks – a school focus – and Japanese language teaching.

Rosa described the significance of her co-teaching with teachers of different specialties in a four-classroom space. This co-teaching enabled her to combine resources and expertise. She highlighted how introducing PBL significantly bolstered her STEM teaching:

> *We're so vested in this [approach] that we spend every day – we're talking about ‘How will we get them toward the next step?’, and ‘Who's going to help us?’, and ‘What do they need to know?’ And I think … the fact that our team is very cohesive and we're working with each other… makes it a very easy job to do.*

Definition of STEM. Rosa described STEM as more than a single challenge, deeper than one activity, and more integrated than single subject teaching. Her approach encapsulated the team-teaching and project-based environment in which she works. Rosa and her co-teachers used a number of strategies to support students’ development of conceptual knowledge around STEM.

Planning process. Rosa explained her detail-rich approach to STEM unit planning. She felt that she was fortunate because her school provided paid planning days for the teaching team with whom she works. On these planning days, developing a term-long STEM unit, Rosa and her co-teachers started with one of the key learning areas. They identified required curriculum outcomes, then moved through other learning areas to identify ways to integrate content. Her comment below illustrated the amount of curriculum coverage in her unit plan[7]:

> *What we did on planning day is we each look at part of the Victorian Curriculum… so we will look at Science, and say, 'This ties in with what we want to do,' then 'This ties in with this'… so we've got inquiry skills, questioning and predicting, planning and conducting experiments… We literally go through the whole curriculum and explore what could apply.*

Rosa detailed a sophisticated content knowledge, making explicit the science, technology, engineering and mathematics that her students would be assessed on. She observed that a design brief aided students in understanding what would be required, noting: "*The expectations are there for their exhibition and what we're looking for.*" She highlighted each of the key learning areas content, accessible to students via *Google Docs*:

> *For science, they've got to show us what they've tested and measured, including their scientific method, and their inquiry... The technology part, they've got to provide – they will be exhibiting… a photograph of their sketches or notes. They have a science journal, which includes notes and diagrams, and things. Next week they start designing on TinkerCAD and SketchUP… The engineering, that will be the product that they*

[7] See also: Appendix 3 for an excerpt from Rosa's unit plan.

> *make. Maths will be all the measurements and the data they have collected and used.*

Students were required to design a SMART goal and plan their projects to address specific criteria. Rosa emphasised that students don't just know what they need to know, but that a large part of her role and her co-teachers' roles is workshopping students to understand conceptual knowledge that was needed to address the design brief requirements. She explained:

> *Workshops come out of just what the students need … They tie in closely with what they need to know through planning documents… like, we've been through chemical composition of water, and stages of doing graphs. We've done the scientific method. Workshops are designed around the curriculum and content that they need to know, as they need to know it.*

Rosa identified that her project-based learning approach was deeply embedded in the classroom. Students had spent the whole first term developing necessary skills to work on projects throughout the coming year. She spoke about the scaffolds and supports that she used with students to track projects and keep work going. She illustrated one strategy for tracking projects:

> *Because a project can fall off the tracks very easily and we have a lot of projects on the same topic, but with different ideas and foci, the eduSCRUMs allow us to meet with every project group every day… The SCRUMs drive the planning for the next few weeks.*

Explicit teaching and guiding groups were highlighted. She spoke about the use of the eduSCRUM (Delhij, Van Solingen, & Wijnands, 2015) process to support each of the co-teachers' explicit instruction with students.

Assessment process. Rosa identified several strategies that she used for assessment with students, from built-in formative assessment of conceptual knowledge through to summative tasks to demonstrate achievement to the standard of the design brief. She spoke about assessment against the design brief:

> *You know, we would be looking for them – in the design brief we are looking for them to address each component of each subject in STEM, so, if they tick off all of the things, I guess we have a checklist of the STEM part. Then we have a rubric for the soft skills that we'll be looking at. You know, 'Have they used science inquiry?' 'Have they, in their SMART goal, considered the ethics or the affordability of their product for people in third world countries?' … looking back on the planner and trying to make connections between what they've said and what we planned.*

Rosa described students' ongoing self-assessment of General Capabilities and STEM skills as an integral part of her teaching. She suggested that students collecting evidence about their own development was helpful as they could see changes in their development of desirable behaviours over time.

> *We give them a rubric at the end. It's – the only time we're really using a rubric is for them to assess their soft skills, and we compare that with the history project rubric [Term 1].*

Rosa collected evidence from students in a number of other ways, including the assessment of the final product. This took form in a multifaceted approach to evaluation of the final product. She explained:

> *There’s always an end product. There's always something visible. For us this time it's a physical product. This is a really visible explanation of how they have understood the content throughout the term. We've got all their Google work that they've collaborated on. We've got access to all their planning, all their designs.*

Teacher-participant 4: Stephanie

Background and context. Stephanie teaches year 7 class at a high socio-economic, north-eastern Adelaide public school. Stephanie was identified as a participant in the study due to her innovative practice and participation in a Year 7/8 STEM collaboration project.

Stephanie described a project, which she was leading, that brought year 7 primary school and year 8 secondary school classes together and aimed to support primary students’ transition into secondary school and to access the expertise of other teachers and students in their STEM learning. This was the main project that she spoke about during the interviews.

[For the 7-8 project] we set our kids a question about ‘Could they build a self-sustaining food source on Mars?’, and then we got them to do a whole lot of research, obviously on the conditions of Mars.

Stephanie described a challenge with her student-led approach to projects, requiring her to provide students with additional support and scaffolding in project management, and self-directed learning. She suggested that, for some projects:

> *It took more scaffolding than we [the teachers] thought that it would… The research and answers that they came up with… [it was] really interesting, but in order for this project to work it needed to have a little more scaffolding.*

Definition of STEM. Stephanie's definition of STEM teaching fits with a teacher who looked for students to develop the depth of knowledge and understanding necessary to excel in the future.

> *I think that quite often we forget that, in order to teach STEM, we have to have that in-depth content knowledge, and I think… sometimes we say to kids, 'Build the tallest tower,' but we don't get into that in-depth 'Well, what maths are you using? What science are you using?', that kind of thing. So, for me, it's first of all making sure that I, the teacher, have that content knowledge, but also transferring that over to my kids, and not doing it as a separate subject; making sure that it fits.*

Planning process. When asked about planning, Stephanie reflected on the influences on the basic design of this project through the collaboration with the high school involved:

> *The five teachers work together to co-design then co-deliver… It's up to us what we get them to do, [but] it has to have a STEM base. The high school has a focus on sustainability, aviation, and computational thinking… so our first one [project together] was a biosphere.*

Stephanie acknowledged that, while collaboration was an important part of the project, her priority was higher-order thinking. She elaborated:

We're here to get that higher order thinking, where they are thinking about a problem, thinking about solutions, and new and innovative ways to do it.

Stephanie explained that student teamwork was important. Having her students work in key learning area groups provoked learning experiences. The teams cycled through different key learning areas and skills from the Australian Curriculum. She explained that this process ensured that her students were able to explain concepts they had learned to others.

We had a leadership team; they were some kids who really wanted to be leaders... Then we had a communications team, a maths, science, technology and engineering [team]…, and a trouble-shooting team… Kids had to be a member of at least two teams.

Linking the team approach to students' understandings, Stephanie explained the reasoning behind her planning of students' learning:

It's quite intentional for them and we have learning objectives, … 'How will I show what I know?'

Stephanie suggested that in her planning she looked for opportunities for students to reflect often –

making sure that … they were able to reflect. 'Justify your thinking. What went well, what didn't? What maths did you use? What science?'

Stephanie noted that, especially when students were not able to articulate their knowledge, she would often run workshops with them, in groups or one-on-one, to make sure that she knew they had the critical conceptual understandings before moving to the next milestone in the project.

Assessment process. Stephanie spoke at length about how she regularly assessed students' understanding of the concepts relevant to the biosphere project.

> *With the biosphere, they'll do a little assignment on how biospheres work, and they had to use their own designs of biospheres to explain [that].*

Stephanie also spoke about her use of *Google Classroom* to facilitate assessment of students' learning*:*

> *We have Classroom quizzes… I could then get some data to make sure they were understanding about the science… There was… quite a lot of hints and questions of 'Do you think, is this the best way?'*

Stephanie's explanation of her planning approach detailed how she aligned her assessments to students' self-direction. She explained aligning the curriculum:

> *I found that what was happening was I was able to assess different kids in different groups on the different things… Of course, you have to be really careful because you want kids to know what they're being assessed on… They then get given rubrics of what each particular child is [working on] … We tend to work on those together.*

Stephanie noted that one of the challenges she faced in students' direction of projects was planning for assessment. She suggested that she tended to plan assessment responsively, and following explicit teaching time, rather than in advance of the unit. She emphasised:

But I do find the assessment planning at the beginning, it – it's probably my biggest problem.

Stephanie also suggested that key learning area (disciplinary) content is not the only thing assessed in her classroom. She detailed her emphasis on General Capabilities:

Personal and social capability, and critical and creative thinking I guess for me are the two big ones… It's important that kids know that those are actually the skills that are going to get them… where they want to go.

Noting the potential difficulties for some students, Stephanie reflected on her students’ ability to embrace the opportunities that were provided during the collaboration and learning about the biospheres:

I sort of thought, ‘Is it a bit big?’ You know, like, they're primary school kids. But they really rose to that and they took it really seriously.

This section has detailed the views of the teacher-participants in relation to the research questions that guide this study. Each participant provided valuable insight in relation to their planning of interdisciplinary STEM learning, and their collection of evidence, and assessment of students’ learning. These sections provide empirical evidence for discussion in the next section of this thesis.

Chapter 5: Discussion

This chapter discusses the findings of the study in relation to the research questions, and literature reviewed. The first section explores the definitions the teacher-participants ascribed to their STEM teaching, in relation with content and pedagogic knowledge (CK and PK), and compares their approach to the literature. The second section elaborates on the teaching approach of the teacher-participants, exploring the gold standard PBL practices they demonstrated, and links the TPACK they draw on in designing interdisciplinary STEM learning experiences. In the third section, the teacher-participants' practice in their collection of evidence is explored in relation to the different ways of knowing of the Kalantzis and Cope (2008) model. Finally, the assessment practices of the teacher-participants are elaborated, in relation to the themes identified in their assessment praxis, drawing together formative and summative assessment strategies in combination with their PBL approach.

Diversity of STEM definitions

The previous chapter explored teacher-participants' definitions of STEM, beyond the acronym. The definitions from the teacher participants provide insight into their STEM epistemological stance by clarifying their alignment with the practices and principles they ascribe to STEM teaching. As highlighted in the literature review, STEM teaching is conceptualised in a range of ways from describing discrete learning areas through to an interdisciplinary approach (Education Council Secretariat, 2015;

Sanders, 2008; Tytler et al., 2008) [8]. The teacher-participants' definitions of STEM were markedly similar. Beyond the acronym however, they viewed STEM teaching as an interdisciplinary approach, one that brought together many key learning areas and General Capabilities (ACARA 2017).

The teacher-participants' valued similar attributes, to each other and literature, in their definition of STEM teaching, including an increasing need to focus on students' ability to demonstrate problem solving skills, life-long learning abilities and adapt to challenges, and that these abilities are developed through STEM learning experiences (Marginson et al., 2013; Prinsley & Johnston, 2015; Rosicka, 2016). Importantly, Stephanie emphasised that: "*In order to teach STEM, we have to have that in-depth content knowledge*". This understanding of the content knowledge (CK) (Mishra & Koehler, 2006, 2008) required was seen across the teacher-participants interviews, detailing sophisticated linking with curriculum, and evolving into a shared description of interdisciplinary STEM learning experiences that were conceptually deeper and more challenging than a stand-alone activities, and that drew in content and skills from across the curriculum (ACARA 2017; Rosicka, 2016).

The teacher-participants also noted how inclusion of both hands-on activities and workshops that support conceptual knowledge development was significant. Consistently, the teacher-participants spoke about hands-on approaches providing

[8] As noted, literature reviewed regarding the definition of STEM teaching tended towards a secondary schooling focus on STEM where different assumptions may be made about the daily practice of teachers. In Australia, typically, in secondary schools students move from class to class, each focussing on different disciplines with a teacher who is a specialist in that area. In primary schools it is typical for students to spend a majority of their school week with one teacher, and one or two specialist teachers.

opportunities for students to apply their learning in new and creative ways, while also being supported to develop STEM knowledge through workshops, as Henry emphasised:

> *Pure explicit teaching on a particular topic … sometimes that can be actually really beneficial in that it actually prompts the thinking*.

This finding is consistent with those of Mehta et al. (2016) who identified STEM as an opportunity to connect abstract ideas to hands-on applied STEM learning.

This common epistemological stance on STEM teaching, in agreement with the inclusion of learning areas in the acronym, the value of development of content knowledge and skills in students, and seeing the teaching of STEM as an interdisciplinary learning experience illuminates the approach of the teacher-participants to STEM, explored in the next section. This finding may be explained by the fact that these participants were all skilled primary school teachers, working in Australian schools, and keenly invested in the implementation of STEM teaching.

Teachers' knowledge in the planning of interdisciplinary STEM learning experiences for primary school students

This section discusses the results in relation to the first research question. While teacher-participants shared many common traits in their STEM definitions, this section explores the teacher-participants' STEM planning and practice in relation to the gold standard project-based learning (PBL) approach explored in the Literature Review (Larmer et al., 2015).

As highlighted in that chapter, project-based learning (PBL) is considered a crucial constructivist approach to STEM education (Capraro & Slough, 2017;

Education Council Secretariat, 2015). A PBL approach also exemplifies a sound development of teachers' TPACK, where to effectively design learning experiences for students, combinations of each knowledge type are required. Further, tensions explored highlighted the need for rigour and reflexivity in teachers' practice of PBL, notably alignment with gold standard PBL (Larmer et al., 2015), to ensure rich and high quality learning experiences are designed for students. Congruent with this was the teacher-participants employment of high quality PBL as a basis for their planning of STEM learning experiences. Each teacher-participant, as outlined in the results, used PBL as their approach to planning and implementation of STEM.

Teacher-participants' identification of PBL as their main approach resolves tensions, explored in the Literature Review, pertaining to issues of a lack of clarity in approach to STEM teaching (Chapman & Vivian, 2017; Education Council Secretariat, 2015). Consequently, this section focusses on teacher-participants alignment with the gold standard PBL model in addressing the first research question that guided this study: *What knowledge do teachers draw on when planning interdisciplinary STEM learning experiences for primary school students?*

As a tool to understand the subtle differences in PBL practice, the gold standard framework (Larmer et al., 2015) is employed. This thesis presents a table of teacher-participants' practices in relation to the results of this study, and the gold standard PBL model, the elements of which are presented on the vertical axis of the table, with the teacher-participants presented along the horizontal axis. This table provides an opportunity to compare the key results against each of the gold-standard elements, across each of the teacher-participants. For clarity, each element of the gold standard PBL is expanded below as a tool for analysis.

Teacher-participants value of PBL teacher practice elements	Henry	Kate	Rosa	Stephanie
Project Design and Planning	Starts with a project brief and has students reframe the learning to demonstrate understanding	Starts with a strong project brief and rubric and has students pair-share their understanding	Starts with a project brief, SMART goal, and has students share their understanding	Starts with gauging students' interest in a range of relevant topics, and designing learning around interests
Aligning the Project to Standards	Aligns projects against the Australian Curriculum, considering General Capabilities and Key Learning Areas Uses technologies learning area as a starting place	Aligns projects against the Australian Curriculum, considering General Capabilities and Key Learning Areas Uses science learning area as a starting place	Aligns projects against the Australian Curriculum, considering General Capabilities and Key Learning Areas Uses science learning area as a starting place	Aligns projects against the Australian Curriculum, considering General Capabilities and Key Learning Areas Uses science learning area as a starting place
Culture Building	Works to build culture in the classroom around success and development of common skills	Works to build students STEM skills, and collaborative skills throughout each project	Works to build students skills for engaging with PBL throughout the year, with ongoing emphasis on collaboration	Works to build students skills for engaging with PBL throughout the year
Managing Project Activities	Guides students' projects with interventions	Guides students on their projects throughout	Uses SCRUM project management to help students self-guide projects throughout the year	Uses project management techniques to help students self-guide projects throughout the year
Scaffolding Student Learning	Uses a series of sophisticated scaffolds to help guide students' learning	Uses a series of scaffolds to help guide students' learning and to understand the concepts they are drawing on	Uses a series workshops and guiding activities to facilitate students' learning	Uses a series of scaffolds to help guide students' learning and to understand the concepts they are drawing on
Assessing Student Learning	Explored below	Explored below	Explored below	Explored below
Engaging and Coaching Student Performance	Helps students develop project plans, create their projects, and provides guidance and advice throughout the project	Helps students develop project plans, create their projects, and provides guidance and advice throughout the project	Helps students develop project plans, understand the goals of their learning, and provides guidance and advice throughout the project	Helps students develop project plans, facilitates student direction, and provides guidance and advice throughout the project
KEY	High Value	Balanced	Low Value	Not explored

Table 2 Teacher-participants' praxis against the Gold Standard PBL elements

Project Design & Planning. Each of the teacher-participants starts with a 'hook': a stimulus that will engage students in the classroom learning, which often originates in issues and interests drawn from their students' lives. This expands on a prevalent theme in the literature, being the need for authentic connection with students' lives (Mehta et al., 2016; Prinsley & Johnston, 2015; Rosicka, 2016). As suggested in the results, teacher-participants reported that their use of an opening prompt initiates deep engagement and stimulates interest for most of their students, and helps students understand the authentic contexts in which STEM learning, and 'real world' STEM takes place (Goodrum, Hackling, & Rennie, 2001; Kelley & Knowles, 2016; Lyons, 2005).

This starting point, drawing from real issues and experiences of students, aided the teacher-participants in their alignment of the learning design with standards[9]. From these stimuli the teacher-participants designed a project brief, a schematic that students would follow to complete the project that they were assigned. This took various forms, drew on various elements of the curriculum and desired different outcomes. This is explored below.

Align to Standards. As emphasised by Larmer et al. (2015) a critical element of gold standard PBL is alignment with standards. In the Australian Curriculum context this would be considered the achievement standards. The teacher-participants each designed their STEM learning by: drawing on the Australian Curriculum (ACARA

[9] In the context of gold standard PBL, 'standards' refer to the curriculum, capabilities, and requirements placed on teachers by the system in which they work (Larmer et al., 2015). For the purpose of this study, these requirements are considered to be the Australian Curriculum as a source of learning materials, and the STEM School Education policy (ACARA 2017; Education Council Secretariat, 2015).

2017) or the state-variant (Victorian Curriculum and Assessment Authority [VCAA] 2017); aligning their planning to the key learning areas and content descriptors; and targeting students' progress toward the achievement standards (ACARA 2017; Larmer et al., 2015).

Starting with a stimulus in mind and drawing on the curriculum content through one of the key learning areas was common among the teacher-participants. This approach initially appears to fit with the first of the two content models for STEM teaching raised in the literature review. The first content model, where the teaching of STEM fits within a science, technology or mathematics lesson and focusses on the primary learning area within that subject (Hunter, 2017; Marginson et al., 2013), could be considered a good starting point; however, the teacher-participants emphasised that they were able to bring in many elements of different key learning areas and General Capabilities. Combining many learning areas informs a series of PBL learning tasks that incorporate content and concepts from disciplines within STEM (Hunter, 2017; Tytler et al., 2011).

A core part of the STEM planning for these primary school teachers includes drawing on knowledge of curriculum that encompasses each of the STEM acronym key learning areas. Additionally, each teacher-participants' practice can be aligned with Sanders (2008) definition of STEM, as each brought together more than one key learning area, and general capability in their approach to STEM PBL (Capraro & Slough, 2017). This alignment with the curriculum symbolises a sophisticated understanding of the content knowledge (CK) necessary to teach STEM (Mehta et al., 2016; Mishra & Koehler, 2006, 2008). The next section explores the culture of inquiry developed as a result of using PBL.

Build Culture. Larmer et al. (2015) prioritise the establishment of an inquiry culture where students can be independent, undertake inquiry, and attend to the quality of their process in production. As indicated in the results, the teacher-participants each dedicated parts of their time to building a culture in their classroom where the sustained inquiry of PBL could thrive (Larmer et al., 2015). Two predominant approaches to inquiry culture building were evidenced in the teacher-participants praxis. These are explored below.

The first approach saw teacher-participants working to build an inquiry culture around PBL through scaffolding and supporting students' learning as they progressed through the projects. This approach also revolved around many of the other tenets of gold standard PBL; including giving students an authentic audience, promoting their autonomy in the creation of products, and building a classroom culture of inquiry (Larmer et al., 2015). This approach is particularly effective, and supported by literature, as teacher-participants worked toward students' development of STEM skills and interdisciplinary metacognition (Becker & Park, 2011; Hudson et al., 2015; Rosicka, 2016) by engaging them in cross-disciplinary thinking in conjunction with project management skills and reapplying learning in appropriate ways (Kalantzis & Cope, 2008).

The second approach saw teacher-participants building an inquiry culture, with their students, that would persist throughout the school year. This approach developed students' self-direction and focused on skill development in the beginning of the year, with deeper STEM projects being employed as students' skills in PBL improved. Both approaches valued students' development of skills related to the other tenets of gold standard PBL (Larmer et al., 2015); however, this approach relied on students developing these skills at the beginning of the year, allowing for the teacher-participants to engage in projects that students managed, thereby linking more closely with students' lives, and shifted responsibility for project management to students.

These approaches may indeed encourage students to develop skills that relate to workplace requirements for STEM in the future, by developing team work skills, and other General Capabilities (Andrews, 2015; Chapman & Vivian, 2017; Prinsley & Baranyai, 2015). Effective development of students' skills, like those in these approaches, require teachers to develop sophisticated pedagogical content knowledge (PCK) (Mishra & Koehler, 2006, 2008). This enables them to support students' learning through the development of project management, and other interpersonal skills.

The building of inquiry culture with a PBL approach was aided by teacher participants' use of tools and scaffolds to assist students' skill development. For example, Kate used the 6D's of Solutions Fluency[10] (Crockett et al., 2011) in conjunction with Kagan (1994) cooperative learning strategies to support the inquiry culture in her classroom. She highlighted how these strategies encouraged students to go beyond the initial scope of the learning task, with students being "*more creative than I expected them, or envisioned the task to be*".

Arguably, students engaged in a culture of inquiry with PBL as the main approach to STEM teaching have opportunities to display engagement and interest in

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[10] This fluency involves: students 'defining' their problem and creating a plan; 'discovering' information relevant to their product; 'dreaming' about the possibilities; 'designing' a clear map of how to get to their end goal; 'delivering' their product; and 'debriefing', where students reflect, self-assess and peer-assess (Crockett, Jukes, & Churches, 2011).

STEM learning that goes beyond a superficial participation in learning, potentially encouraging their interest in life-long STEM learning (Mehta et al., 2016). These two approaches develop a classroom culture that values students' skill development, produces a product, draws influence from students' lifeworld, and develops students' STEM skills (Prinsley & Baranyai, 2015; Rosicka, 2016; Tytler et al., 2011). It also requires teachers to display complex PCK, a key knowledge for teachers planning interdisciplinary STEM learning experiences (Mehta et al., 2016; Mishra & Koehler, 2006, 2008). Another key consideration for teachers' PCK is the development of students' project management, and the management of student activities, explored below.

Manage Activities. Project management is considered a more challenging aspect of PBL (Larmer et al., 2015) and, as noted by Rosa, if not well monitored "*a project can fall off the tracks very easily*". Rosa employed eduSCRUMs to keep STEM projects 'on track'. EduSCRUMs are a complex project management practice borrowed from computer science (Sutherland & Schwaber, 2013) to track projects. This process helped Rosa, and her co-teachers, to monitor students' progress for each project visually, using post-it notes and boards around the classroom, divided into three sections; 'Not Started', 'Progressing', and 'Finished' (Delhij et al., 2015).

Teacher-participants also utilised ICT tools to help keep track of projects. Stephanie demonstrated this with her use of *Google Classroom,* which enabled her to actively track students' progress through learning tasks. Stephanie, Kate and Rosa used *Google Docs,* allowing students to respond to teacher and peer feedback on the progress of their ongoing projects. Stephanie also indicated how *Google Classroom* can be used to facilitate conversations between parents and their students, making students accountable to more people and adding authenticity and reality to their project management (Johnson, 2013; Larmer et al., 2015).

Managing students' activities draws on teachers' TPACK, requiring them to understand where their students are up to (PK), and be able to provide advice and support through the use of ICT tools (TCK).

Scaffold Student Learning. Supporting students to engage with the content knowledge and skills required to understand the sophisticated STEM learning they are participating in is a key part of gold standard PBL (Edelson, Gordin, & Pea, 1999; Larmer et al., 2015). Teacher-participants used a range of strategies, explored in the results and the 'project design' section above, to engage their students in projects. Each teacher-participant provided students with the opportunity to receive feedback from a range of sources, in a range of ways, and to revise and improve their learning. By coupling this with formative assessment strategies (Wiliam, 2011), and the delivery of projects to authentic audiences, the teacher-participants exposed their students to the practicalities of STEM projects.

Students were provided with authentic contexts for their STEM learning and, as noted in the literature review, this may encourage students to engage with the learning at hand. However, some content requires scaffolding and support from teachers to be properly understood without misconceptions developing (Larmer et al., 2015). One solution to scaffolding students' learning was employed by Stephanie, who had students work in two or more discipline teams and asking students to share their understanding of concepts with a peer to authentically describe their learning and share the learning experience. This process also ensures that students maintain sustained inquiry (Larmer et al., 2015) and helps students understand the complex conceptual knowledge required for STEM learning (Johnson, 2013; Stohlmann et al., 2012; Tytler et al., 2008).

As previously discussed, the support of students' development of advanced conceptual knowledge and skills contributes to their lifelong interest in STEM learning (Chapman & Vivian, 2017; Marginson et al., 2013). The next section elaborates on the teacher-participant's role in the PBL approach, exploring how they engage and coach students for effective STEM learning.

Engage and Coach. To help students develop their conceptual understanding and make meaningful progress in their learning, workshops are required where the teacher acts as a facilitator (Larmer et al., 2015). Each of the teacher-participants' roles as coach of students was summarised in the results above. Two cases below are used to illustrate how the teacher-participants engaged and coached their students.

Rosa used a series of workshops where students rotated disciplines and focussed on areas of need, relevant to progress in their project. This rotation not only exposes students to interdisciplinary metacognition by asking them to think about their disciplinary knowledge in different applications or projects (Kalantzis & Cope, 2008), a key STEM skill, but also helps students to think about problems in new and creative ways (Delhij et al., 2015; Larmer et al., 2015; Rosicka, 2016).

Alternatively, Henry worked alongside his students as a coach (Larmer et al., 2015) to guide them in the project process. He also used this opportunity, in his role as facilitator and guide, to gather evidence of students' learning and help students develop their understandings in a one-to-one mentoring role where students share their learning with him and one another.

Teacher-participants use of PBL in their approach to planning interdisciplinary STEM learning experiences reveals their complex TPACK: a range of strategies for teaching, knowledge in facilitation and coaching, and a variety of ICT tools employed to support and scaffold students' learning have been elaborated above. Similar to the findings of Mehta et al. (2016), while TPACK is known to be a framework to understand teachers' knowledge, and elements of the framework are clear throughout the teacher-participants' approaches, the TPACK framework itself was not present in the interviews. Importantly, as noted in the literature review, these results need to be interpreted with caution as TPACK, connected with gold standard PBL, requires a teaching and learning context (Mishra & Koehler, 2008) to understand how the STEM teaching is taking place. As noted in the literature review, PBL and problem-based learning approaches are the main focus of Australian government policy and much existing research literature (Education Council Secretariat, 2015; Rosicka, 2016), and the four participants are responding as envisioned by policy makers. However, it is important to note that other approaches may be present in different teaching and learning contexts.

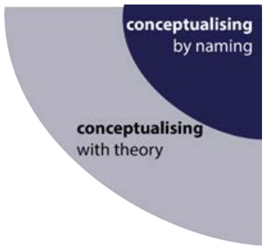
This section has: addressed the question of how teacher-participants' plan interdisciplinary STEM learning experiences for their primary school students; drawn attention to the opportunities and challenges present in STEM teaching, through a gold standard PBL lens, and emphasised how teacher-participants plan and support students' development of the critical STEM knowledge and skills, highlighted in the literature review. It has also revealed the knowledge of the teacher-participants in relation to their TPACK, and the gold standard PBL model.

Evidence teachers use to evaluate their impact on students' learning

This section explores the evidence teacher-participants collect to evaluate their impact on students' STEM learning, bridging their planning and implementation of a STEM PBL (Capraro & Slough, 2017) approach and leading into their assessment of students' work. To explore the value and the actual evidence teacher-participants give to students' development of understandings of STEM content, the Learning by Design (Kalantzis & Cope, 2008) model is employed. The Learning by Design model is made up of four quadrants, each having two levels. These levels, ways of knowing, can be combined, addressed individually, or moved between. This means that in planning and assessment teachers will focus on different areas of the model (Kalantzis & Cope, 2008).

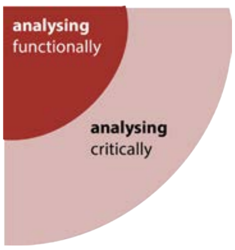
Evidence of experiencing. The experiencing quadrants of the Learning by Design (Kalantzis & Cope, 2008) model may be related to the importance of discovery and wonder when students engage in STEM learning (Mehta et al., 2016)**.** The teacher-participants begin students' experiencing through the incorporation of elements of students' real lives. Kate provided an example of this by addressing the school's 'crow problem'. The crows were swooping and eating garden produce and students were required to look at ways to counteract damage to the garden and school surrounds, drawing on their experiences and knowledge.

Classroom discussions or brainstorms about how they might like to embark on the learning journey provided evidence for teacher-participants which helped them design engaging learning opportunities for their students. This improves the possibility of these learning experiences engaging students in long term interest in pursuing STEM as a career pathway (Chapman & Vivian, 2017).



Evidence of conceptualising. Valuing students' development of conceptual understanding is a critical part of the PBL approach the teacher-participants employed. In addition, developing a conceptual understanding, especially 'with theory', is paramount to showcasing *"student mastery of several concepts of various STEM subjects"* (Capraro & Slough, 2017, p. 2). The teacher-participants evidenced students' conceptualising with theory, and by naming, through the use of explicit teaching with integrated assessment tasks both formative and summative in nature (Wiliam, 2011). This knowledge type was assessed by teacher-participants to ensure students' developed the necessary understandings to achieve the curriculum achievement standard (ACARA 2017), and was evaluated through the use of submitted assessments. Rosa gave the example of having students do a pre-test to assess their conceptual knowledge in mathematics relevant to the water project they were embarking on. Checking for understanding before embarking on further workshops and learning experiences ensures that students don't miss out on the critical STEM understandings needed for success in their projects (Johnson, 2013; Stohlmann et al., 2012; Tytler et al., 2008).

Evidence of applying. The teacher-participants gathered evidence of students' application of knowledge and skills throughout the hands-on elements of their learning experiences. This element is a challenge for teachers' collection of evidence yet it is easy to observe in their STEM learning experiences as students' knowledge and skills in this quadrant are developed as a result of teachers' planning for practical production of the final product. As a critical consideration for contextualising and making 'real' the learning experiences of students (Rosicka, 2016), the application of knowledge, both appropriately and creatively, is a key part of each of the teacher-participants' planning for STEM learning experiences (Kalantzis & Cope, 2008). Indeed, teachers' evaluation of the final 'applied' product students create, to address the PBL design brief, forms a key part in the design of STEM learning (Tytler et al., 2008; Wiliam et al., 2004).



Evidence of analysing. The final quadrant of the Learning by Design (Kalantzis & Cope, 2008) model connects with the previous quadrant, applying, in that the analysis often draws on knowledge that has been applied to a product. The teacher-participants collected evidence of students' analysis through the assignment of written reflections on the students' development of conceptual knowledge, as detailed in the Results chapter. Reflection on completed work is emphasised in the teacher-participants' value of learning from what students have presented, and by creating many drafts before presenting a final product to an authentic audience (Larmer et al., 2015).

Teacher-participant focus. Teacher-participants began their planning in different ways and had different foci in their planning of students' learning, this effected their collection of evidence, and their main focus on the elements of the Learning by

Design model. Henry, for example, used the Technologies learning area as the focal point for drawing together 3D printing and product design, with an ultimate goal of students producing a saleable product. Arguably, the skills required for this focus lie in the apply quadrant of the Kalantzis and Cope (2008) model, related to his specialist teacher role. Classroom teachers though, focussed more on conceptual understandings, where a focus on the thinking skills from the curriculum is appropriate. Another example can be drawn from Rosa’s interviews where each quadrant of the Kalantzis and Cope (2008) model is addressed, potentially because of her dedication to term-long units of PBL work.

In summary, these contrasting examples demonstrate a need for teachers to be intentional about the understandings and skills students will develop to ensure understandings required by standards are acquired (ACARA 2017). The Learning by Design model (Kalantzis & Cope, 2008) is a sound recommendation for teachers implementing a STEM PBL approach, preventing possible pitfalls and assumptions in understanding students’ knowledge.

This section has outlined how the teacher-participants collected evidence of students’ development of STEM knowledge and skills. The Learning by Design (Kalantzis & Cope, 2008) model provided a useful lens for understanding the value that teachers place on the ways in which students develop conceptual understandings and skills, which once again demonstrates their commitment to a balanced development of students’ STEM understandings. Arguably, this section emphasises the possibilities of a STEM PBL (Capraro & Slough, 2017) approach to develop students’ understandings in different ways, in addition to providing teachers with multiple opportunities to collect evidence in both formative and summative, formal and informal ways.

Teachers' assessment of students' learning in STEM

This section explores the formative and summative assessment strategies employed by the teacher-participants in addressing students' STEM learning; their use of technology for assessment; linking of assessment to curriculum related to STEM; the use of assessments as a tool to help students improve; and finally, how peer and self-assessment strategies are employed in their classrooms. Given the dearth of STEM-specific assessment literature noted in the literature review, the areas of exploration in this section are drawn from themes present in the teacher-participants interviews, and formative assessment literature in general (Fisher & Frey, 2014; Wiliam, 2011).

As a tool to understand the STEM assessment practices of the teacher-participants this thesis presents a table. Themes from the individual interviews, and from assessment strategies more broadly, are presented on the vertical axis of the table, with the teacher-participants presented along the horizontal axis. This table provides an opportunity to compare the key results between each of the teacher-participants. For clarity, each element is expanded below as a tool for analysis.

Value placed by teacher-participants' on assessment	Teacher-participant	Henry	Kate	Rosa	Stephanie
	Formative assessment of components in project	Uses learning conversations, ongoing formative assessments	Uses rubrics and ongoing assessments with students	Uses rubrics and ongoing assessments with students	Uses rubrics and ongoing assessments with students
	Summative assessment of the project as a whole	Identifies successful completion of the project as assessment task, but provides opportunities for revision	Identifies successful completion of the project as assessment task	Identifies successful completion of the project as assessment task	Looks for quality in process, not in the final project presentation
	Use of technology to assess students' learning	Occasional use, part of formative assessment process	Has students record learning stories (video, audio) and share with peers and parents	Uses *Google Docs* to share real-time feedback with students, monitor progress	Uses *Google Classroom* to provide outlines including project briefs, feedback to students, and monitor progress
	Value of links with curriculum	Identified in initial planning, not in students work	Uses a post-planning approach to map student learning to curriculum	Uses explicit rubrics with curriculum-oriented language	Uses explicit curriculum links directly with students
	Use of assessment as reflection tool for students	Students provided opportunities to revise and develop on their work	Students provided opportunities to revise and develop on their work	Students provided opportunities to revise and develop on their work	Students provided opportunities to revise and develop on their work
	Use of student self/peer assessment	Students provide guidance to each other but do not peer assess	Explicit use of student self/peer assessment	Explicit use of student self/peer assessment	Explicit use of student self/peer assessment
	KEY	High Value	Balanced	Low Value	Not explored

Table 3 Teacher-participants' alignment with themes present in the individual-interviews against assessment of students' STEM learning

Formative assessments. Formative assessments are a key part of developing students' understanding of STEM learning, maintaining engagement, developing self-direction and encouraging students' innovation (Tytler et al., 2008; Wiliam et al., 2004). With existing literature suggesting that formative assessment practices were used by teachers in the assessment of STEM learning[11], the finding that each teacher-participant employed a mixture of formative and summative assessment tasks was not surprising; however, subtle differences in the way they assessed highlighted a need to explore their assessment practices further.

To expand on the formative assessment strategies employed by the teacher-participants, two cases are expanded below.

For Henry, in his role as facilitator and guide, opportunities arose to gather data about students' learning. He assessed students through a range of formative assessment strategies, including drawing evidence from entering into learning conversations, and using a number of scaffolds with students to track their progress in their projects. Acting as coach and assessor he was able to intervene when students' projects may have been deviating from desired progress.

Rosa's assessment had two key stages: students' development of understandings, conceptual knowledge, and skills (Kalantzis & Cope, 2008) in workshop time; and students' application of knowledge and skills in project work (Larmer et al., 2015). Rosa collected evidence of students' learning from almost every learning encounter they had, from workshop content to notes and reflections on their

[11] In a limited capacity, the general findings of the literature review indicated initial research into the use of formative assessments in STEM (Tytler et al., 2008).

projects (Wiliam, 2011). The end product was an assessment piece: "*This time it's a physical product, so this is a really visible explanation of how they have understood the content throughout the term*". She also monitored students' progress along the way with formative assessment: *"We've got all their Google Doc work that they've collaborated on, we've got access to all their planning, all their designs."* Students' reflection on attainment of their SMART goals, including self-assessment and peer assessment, was also a valuable part of the process.

These two approaches, while both employing formative assessment strategies, highlight the differences in both the approaches to STEM teaching, and the strategies for assessment of students' learning. These approaches also raise questions about the use of technology, and the summative assessments that teachers may employ to assess students' learning in STEM. These are explored below.

Summative assessment of projects. As PBL requires students' production of a final product, there are opportunities for teachers to assess students' learning with both formative and summative tasks. Connecting students' learning to real-world contexts, particularly in regard to delivery of a final product, is a goal of STEM learning (Capraro & Slough, 2017; Education Council Secretariat, 2015; Mehta et al., 2016). Use of authentic audiences, such as those in a PBL product (Larmer et al., 2015), connect well with summative assessments of students' completed projects. While all teacher-participants overwhelmingly valued the process of producing the PBL product, Henry, Kate and Rosa also saw evaluation of students' successful completion of the final product as a critical stage. This evaluation was designed in their planning, and applied at the completion of the unit. Henry and Kate provided students with opportunities to revise their work and Henry gave students opportunities to resubmit.

This practice employs formative assessment strategies in summative tasks (Wiliam, 2011).

Use of technology to assess students' learning. Another theme of teacher participants' assessment was the use of technology to assess students' learning, manage projects, and help students communicate and collaborate. Not only did teacher-participants utilise the ICT general capability in developing students use of ICT tools to achieve their STEM learning goals, but the teacher-participants themselves drew on TPACK[12] to assess students' STEM learning. ICT and technological knowledge are paramount in constructing and communicating information in order to solve complex STEM problems for teachers and students (Akgun, 2013; Ramírez-Montoya, 2017). This is epitomised in the teacher-participants use of ICT tools for formative assessment, and explored against two of the cases below.

Kate brought technology into her assessment of students' learning by using *Seesaw,* a formative assessment tool that enables students to share their work with their teacher, parents, and fellow students. She gave the example of asking a student to produce "*a Seesaw video recording: 'Go describe what you've done, what you've learnt, show something on there [your project,]'"* that would describe the student's understanding of a concept or problem. This evidence subsequently informed her assessments.

Stephanie's assessment drew on technology, including the use of *Google Classroom* and *Google Docs,* to gain a clear picture of students' progress. She

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[12] Knowledge types, opposed to framework.

expressed that the use of technology in assessment is critical because, before she started using these technologies, it was significantly more difficult and time consuming to assess students' STEM learning. Technology enabled students to work on tasks in real-time, receive feedback from their peers and Stephanie, as the teacher, and to address feedback during the learning process. Stephanie also emphasised how this use of technology placed the responsibility for much of the collection and presentation of evidence of student learning with students (Wiliam, 2011).

A deeper engagement with ICT tools for STEM learning is illustrated above, not merely a superficial engagement with technologies without purpose. This significant engagement with ICT tools is highlighted as a critical element of STEM learning (Akgun, 2013; Rosicka, 2016; Tytler et al., 2011).

Use of assessment as a reflection tool for students. Another theme arising from the interviews was students' abilities to develop their skills when offered opportunities to revise and resubmit their work as their knowledge developed. Use of assessment as a tool for students' reflection is explored in two cases below.

Kate's students were encouraged to independently reflect on peer feedback and what they themselves think about their learning journey. Following this independent reflection, students were invited to collaborate on their feedback with a peer, or in a group, about changes or improvements. Similarly, Henry's students were provided opportunities to reflect on the product they produced as a result of their participation in the PBL, and the opportunity to revise their work when potentially not meeting the targets set for the task. This use of feedback to inform future design of lessons, and to encourage students to reflect and respond to feedback is in keeping with Wiliam's (2011) suggestion that students should be provided opportunities to continue to learn from their feedback.

Use of student self/peer assessment. Formative and summative assessment tasks that employ self and peer assessment for students in STEM learning are another way that teacher-participants aligned with both gold standard PBL, and formative assessment strategies (Larmer et al., 2015; Wiliam, 2011). Asking students to assess their own progress and development both encourages them to reflect, and to take responsibility for their learning. Encouraging them to assess one another's work also provides them with opportunities to develop interpersonal and communication skills, and provides them with an authentic audience with whom to present their learning. These are key parts of developing STEM skills (Becker & Park, 2011; Hudson et al., 2015; Rosicka, 2016).

These critical elements of teachers' assessment of students' STEM learning provide initial contributions to the emergent field of primary school STEM assessment. Acknowledging the lack of specific STEM assessment literature, this section indicated that no specific model exists for teachers' assessment of students' STEM learning. However, as suggested in the Literature Review, the general practices of formative assessment, and the assessment strategies from PBL, provide a good starting place in understanding teachers' assessment of students' learning in STEM. A strong case can be made for the employment of formative assessment in STEM in conjunction with teachers' understanding of the Learning by Design (Kalantzis & Cope, 2008) model to highlight the knowledge and skills students need to develop, resulting from a PBL approach.

This section, and the previous section, have made an initial contribution towards addressing the second research question for this study. While there is still a lack of clarity in the broader context of assessment of primary school students' STEM learning, this study has illustrated some of the similarities and differences in approaches to STEM assessment.

Chapter Conclusion

This chapter has provided a discussion of the findings against the research questions, and literature explored in previous chapters. The TPACK framework, gold standard PBL, and the Learning by Design model have been used to explore teachers' knowledge and praxis in their STEM planning, implementation, and assessment. This chapter has drawn together the findings of the study, and addressed both of the research questions. Having analysed the data from the four teacher-participants, the final chapter draws conclusions about the insights identified, makes recommendations and explores potential for future research.

Chapter 6: Conclusion

This is the first time that the technology, pedagogy and content knowledge (TPACK) framework, gold standard project-based learning (PBL), and Learning by Design have been used together, as research tools, to investigate the STEM practices of teachers. Within the limitations of this study, a range of recommendations are offered advisedly. These frameworks were effective for developing an understanding of teacher participants' STEM practices, and provided some initial insight into the kinds of assessment that teachers undertake in their STEM PBL classrooms. The subsequent findings signal the importance, in teachers' practice, of clear, concise and accessible frameworks for research. Positive pedagogy and innovation outcomes are indicated by the teacher-participants' alignment with gold standard PBL, and the impacts in practice are evident.

In addressing the study's first research question; how teachers plan interdisciplinary STEM learning experiences for primary school students, PBL proved to be the chosen scaffold, demonstrating a multifaceted culmination of teachers' knowledge (TPACK). The PBL approach addresses the recommendation from literature that a constructivist pedagogy is needed to teach STEM effectively (Ramírez-Montoya, 2017). This pedagogy, exemplifying gold standard PBL practices, is present in the STEM teaching approach of all the teacher-participants. Given teacher uncertainty about approaches to STEM and the lack of prescribed approach as highlighted in the Literature Review, finding four highly effective teachers explicitly using PBL points to a successful way forward.

The second research question of how teachers assess students' learning in STEM and what evidence they use to evaluate their impact on student learning, produced illustrations of teachers' STEM assessment practices; the types of data they collect; and how they evaluate their impact on students' learning. This study contributes to existing formative assessment knowledge by elaborating the teacher-participants' STEM assessment practices and mirrors similar assessment strategies to those used in other learning areas (Wiliam, 2011). While no overarching assessment approach emerged from this study, there is clearly room for further research to develop a STEM assessment model responsive to the context (Mishra & Koehler, 2008) in which assessment tools are being used to address policy goals (Education Council Secretariat, 2015).

This study has researched the emergent response of the teacher-participants to the pressures of STEM policy that is calling for: teachers to develop students' positive dispositions toward STEM education and their STEM knowledge and skills; schools to develop strong industry links; and teachers to adopt project-based learning, drawing on sophisticated technology and engineering projects. This study suggests that teachers have responded to calls to develop students' knowledge and skills in STEM, adopted the suggested project-based learning approach, and built sophisticated projects that draw on many of the concepts and skills from the Australian Curriculum. Specifically, the teacher-participants' practice shows strength in their efforts to engage students in STEM, develop students' knowledge and skills, and encourage students towards future STEM interests (Chapman & Vivian, 2017; Education Council Secretariat, 2015).

A range of possibilities arise to address policy concerns. For example, policy calls for inclusion of industry links but this was not yet evident in this study's teacher-participants' work. For primary STEM to have the traction required to meet policy goals, further attention could be given to the ways in which primary schools may develop industry connections, development and delivery of cohesive STEM professional learning for teachers, and further work to help all teachers understand the primary and middle years as *“critical periods when students begin to cement their aspirations for, and confidence in, STEM”* (Education Council Secretariat, 2015, p. 8).

Implications for Practice. This study situated the value teacher-participants’ placed on evidence of students’ STEM knowledge, understanding and skills, against the Learning by Design (Kalantzis & Cope, 2008) quadrants. This proved valuable in identifying teachers’ approaches to collecting evidence of understandings and skills to inform their planning and assessment. When teachers understand the types of knowledge in a model, such as Learning by Design, there are opportunities for self-reflection and further development of teaching skills. This is an important implication for future STEM research, and policy development, suggesting that teachers need to understand how they are developing students’ knowledge and skills so they can teach concepts effectively. This should be a consideration for school leaders, and indeed policy development, because helping teachers to develop students’ STEM knowledge and skills is paramount to success.

Extensive formative assessment strategies were utilised by the teacher-participants. These strategies included: the ongoing assessment of students’ learning; incremental assessment and coaching of students’ skills against the General Capabilities (ACARA 2017); and included sophisticated use of ICT tools in learning tasks, and subsequent collection of evidence from students. These practices, among others demonstrated, not only indicated considered assessment processes, but also addressed several concerns from within literature about innovative teaching strategies and assessment falling behind (e.g. Kalantzis & Cope, 2008). These strategies, as illustrated in the Results section, were varied, depending on the teacher-participant's chosen project context (Mishra & Koehler, 2008).

This is an important consideration for the national collaborative actions of the National STEM School Education Strategy: "online formative assessment tools that help teachers collect and use data" (Education Council Secretariat, 2015, p. 9). Significant investment in pre-service and teacher education and leadership support is needed to ensure development of effective technology use in STEM teaching and assessment.

As suggested in the National STEM School Education Strategy (Education Council Secretariat, 2015), if PBL is to be the main approach, Australian teachers will need further training to effectively implement PBL in their classrooms. It would be reasonable to place an emphasis on high quality professional learning resources for teachers (As suggested in: Education Council Secretariat, 2015) in order to ensure that their practice aligns with the gold standard approach. Falling short of this standard raises three potential challenges: the first is a loss of students' subject knowledge compared to traditional disciplinary approaches to STEM learning areas; the second, an inadequate, unfocussed or poorly implemented approach to PBL will result in a loss of student learning opportunities; and the third relates to the importance of balancing subject-based disciplinary knowledge and the use of interdisciplinary gold standard PBL. As all participants in this study were identified as exemplary, their processes for effectively managing evidence and balance of knowledge and skills illustrates that there is much to be learned from high quality practice to support all teachers.

Recommendations for Research. In addition to the conclusions already drawn, additional research could deliberately push beyond this study's epistemological assumptions into social constructionism, and more fully explore reality as a relative construct and the many possible interpretations which depend on meaning and other systems (Burr, 2015; Crotty, 1998; Lincoln & Guba, 1985). It is important to consider: the range of practices of teachers in the profession; the lived experiences of teachers in response to policy; the nature of new frameworks that may be developed to analyse teachers' praxis; the support teachers in this field require; and bringing new methodologies to the STEM education research space.

The challenges of understanding the actions of teachers, evaluating participants' discourse in their context, and recognising the impact of culture and agency (Archer, 1996) may be more effectively addressed with a sociological approach; adopting a social consructionism frame, and undertaking an immersive study that follows the practice of STEM educators, coordinators, students and parents as they relate praxis and policy, structure and agency, and the barriers and enablers to STEM education, for example, exploration of policy in regards to praxis. Such research may take place as ethnographic studies (Tedlock, 2003; Van Maanen, 1995) or expanded case studies (Burawoy, 1998) and could provide new insight and frameworks for understanding to this nuanced field.

References

ACARA. (2017). *Australian Curriculum: Technologies*. Sydney NSW: Australian Curriculum, Assessment and Reporting Authority Retrieved from http://www.australiancurriculum.edu.au/technologies/glossary - D.

Akgun, O. E. (2013). Technology in STEM Project-Based Learning. In R. M. Capraro, M. M. Capraro, & J. R. Morgan (Eds.), *STEM Project-Based Learning*. Rotterdam, The Netherlands: Sense Publishers.

Andrews, K. (2015). STEM skills the key to Australia's economic success [Press release]. Retrieved from http://www.minister.industry.gov.au/ministers/andrews/media-releases/stem-skills-key-australias-economic-success

Archer, M. S. (1996). *Culture and agency: The place of culture in social theory*: Cambridge University Press.

Australian Curriculum Assessment and Reporting Authority. (2016, December 14). Australian Curriculum: Technologies Introduction. Retrieved from http://www.australiancurriculum.edu.au/technologies/introduction

Australian Curriculum Assessment and Reporting Authority. (2017). Australian Curriculum. Retrieved from http://www.australiancurriculum.edu.au/

Becker, K., & Park, K. (2011). Integrative approaches among science, technology, engineering, and mathematics (STEM) subjects on students learning: A meta-analysis. *Journal of STEM Education, 12*(5), 23-37.

Black, P., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education: Principles, Policy & Practice, 5*(1), 7-74.

Black, P., & Wiliam, D. (2009). Developing the theory of formative assessment. *Educational Assessment, Evaluation and Accountability (formerly: Journal of Personnel Evaluation in Education), 21*(1), 5.

Blackley, S., & Howell, J. (2015). A STEM narrative: 15 years in the making. *Australian Journal of Teacher Education, 40*(7), 102-112.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational psychologist, 26*(3-4), 369-398.

Brears, L., MacIntyre, B., & O'Sullivan, G. (2011). Preparing teachers for the 21st century using PBL as an integrating strategy in science and technology education. *Design and Technology Education: An International Journal, 16*(1).

Bryman, A., & Burgess, R. G. (1994). Developments in qualitative data analysis: an introduction. In A. Bryman & R. G. Burgess (Eds.), *Analyzing qualitative data*. London: Routledge.

Burawoy, M. (1998). The extended case method. *Sociological theory, 16*(1), 4-33.

Burlbaw, L. M., Ortwein, M. J., & Williams, J. K. (2017). The Project Method in Historical Context. In C. R. M, C. M. M, & M. J (Eds.), *STEM Project-Based*

Learning: An Integrated Science, Technology, Engineering, and Mathematics (STEM) Approach. Rotterdam, The Netherlands: Sense Publishers.

Burr, V. (2015). *Social constructionism*: Routledge.

Cantrell, P., Pekcan, G., Itani, A., & Velasquez-Bryant, N. (2006). The effects of engineering modules on student learning in middle school science classrooms. *Journal of Engineering Education, 95*(4), 301.

Capraro, R. M., & Slough, S. W. (2017). Why PBL? Why STEM? Why now? An introduction to STEM project-based learning: an integrated science, technology, engineering, and mathematics (STEM) approach. In R. M. Capraro, M. M. Capraro, & J. R. Morgan (Eds.), *STEM Project-Based Learning* (2nd ed.). Rotterdam, The Netherlands: Sense Publishers.

Cartledge, D. (2010). *STEM – A Technical Renaissance?* Paper presented at the STEM in Education Conference, Queensland University of Technology, Brisbane, Australia.

Chapman, S., & Vivian, R. (2017). *Engaging the future of STEM*. Retrieved from Sydney, NSW: https://cew.org.au/wp-content/uploads/2017/03/Engaging-the-future-of-STEM.pdf

Clare, L., & Aschbacher, P. R. (2001). Exploring the Technical Quality of Using Assignments and Student Work as Indicators of Classroom Practice. *Educational Assessment, 7*(1), 39-59. doi:10.1207/S15326977EA0701_5

Creswell, J. W. (1998). *Five qualitative traditions of inquiry*. Thousand Oaks, CA: Sage.

Creswell, J. W. (2012). *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research*: Pearson.

Crockett, L., Jukes, I., & Churches, A. (2011). *Literacy is not enough: 21st century fluencies for the digital age*: Corwin Press.

Crotty, M. (1998). *The foundations of social research: Meaning and perspective in the research process*: Sage.

Delhij, A., Van Solingen, R., & Wijnands, W. (2015). *The eduScrum Guide* (S. Beaumont, A. Delhij, & T. Gerrits, Trans.). Amsterdam: eduScrum.

Dewey, J. (1963). *Experience and education*. New York: Collier.

Dewey, J., & Small, A. W. (1987). *My pedagogic creed*: EL Kellogg & Company.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the learning sciences, 8*(3-4), 391-450.

Education Council Secretariat. (2015). *National STEM school education strategy*. Melbourne, Australia: Australian Education Council Retrieved from http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/National STEM School Education Strategy.pdf.

Elliott, B., Oty, K., McArthur, J., & Clark, B. (2001). The effect of an interdisciplinary algebra/science course on students' problem solving skills, critical thinking skills and attitudes towards mathematics. *International Journal of Mathematical Education in Science and Technology, 32*(6), 811-816.

English, L. D., Hudson, P., & Dawes, L. (2013). Engineering-based problem solving in the middle school: Design and construction with simple machines. *Journal of Pre-College Engineering Education Research (J-PEER), 3*(2), 5.

English, L. D., & King, D. T. (2015). STEM learning through engineering design: fourth-grade students' investigations in aerospace. *International Journal of STEM Education, 2*(1), 14.

Fisher, D., & Frey, N. (2014). *Checking for Understanding: Formative Assessment Techniques for Your Classroom*. Alexandria, VA: ASCD.

Fortus, D., Krajcik, J., Dershimer, R. C., Marx, R. W., & Mamlok-Naaman, R. (2005). Design-based science and real- world problem - solving. *International Journal of Science Education, 27*(7), 855-879.

Ge, X., Ifenthaler, D., & Spector, J. M. (2015). *Emerging Technologies for STEAM Education: Full STEAM Ahead*: Springer International Publishing.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The status and quality of teaching and learning of science in Australian schools*. Canberra: Department of Education, Training and Youth Affairs.

Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education, 57*(3).

Hudson, P., English, L., Dawes, L., King, D., & Baker, S. (2015). Exploring Links between Pedagogical Knowledge Practices and Student Outcomes in STEM Education for Primary Schools. *Australian Journal of Teacher Education, 40*(6), 6.

Hunter, J. (2017). Switching Middle School Teachers onto STEM Using a Pedagogical Framework for Technology Integration: The Case for High Possibility Classrooms in Australia. In L. Liu & D. Gibson (Eds.), *Research Highlights in Technology and Teacher Education 2017* (pp. 37 - 46). Waynesville, North Carolina: Association for the Advancement of Computing in Education (AACE).

Johnson, C. C. (2013). Conceptualizing integrated STEM education. *School Science and Mathematics, 113*(8), 367-368.

Kagan, S. (1994). *Cooperative Learning* (second ed.). California: Resources for Teachers, inc.

Kalantzis, M., & Cope, B. (2008). *New Learning: Elements of a Science of Education*. Port Melbourne, Victoria: Cambridge University Press.

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(1), 11. doi:10.1186/s40594-016-0046-z

Kilpatrick, W. H. (1918). *The project method: The use of the purposeful act in the educative process*: Teachers college, Columbia university.

Kim, Y., & Park, N. (2012). The effect of STEAM education on elementary school student's creativity improvement *Computer applications for security, control and system engineering* (pp. 115-121): Springer.

Larmer, J. (2014). Project-Based Learning vs. Problem-Based Learning vs. X-BL. Retrieved from https://www.edutopia.org/blog/pbl-vs-pbl-vs-xbl-john-larmer

Larmer, J., Mergendoller, J., & Boss, S. (2015). *Setting the standard for project based learning*. Alexandria, VA, USA: ASCD.

Lehrer, R. (2009). Designing to develop disciplinary dispositions: modeling natural systems. *American Psychologist, 64*(8), 759.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry* (Vol. 75). Newbury Park, CA: Sage.

Lyons, T. (2005). Different countries, same science classes. *International Journal of Science Education, 28*(6), 591-614.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). STEM: country comparisons: international comparisons of science, technology, engineering and mathematics (STEM) education. Final report.

McConney, A. A., Schalock, M. D., & Schalock, H. D. (1998). Focusing Improvement and Quality Assurance: Work Samples as Authentic Performance Measures of Prospective Teachers' Effectiveness. *Journal of Personnel Evaluation in Education, 11*(4), 343-363. doi:10.1023/a:1007974009896

McDonald, J. P. (2001). Teachers Caught in the Action: Professional Development that Matters. In A. Lieberman & L. Miller (Eds.), *Teachers Caught in the Action: Professional Development that Matters*. New York: Teachers College Press.

Mehalik, M. M., Doppelt, Y., & Schuun, C. D. (2008). Middle-school science through design-based learning versus scripted inquiry: Better overall science concept learning and equity gap reduction. *Journal of Engineering Education, 97*(1), 71-85.

Mehta, S., Mehta, R., Berzina-Pitcher, I., Seals, C., & Mishra, P. (2016). 49 Stories That Make an Ultimate STEM Lesson Plan. *Journal of Computers in Mathematics and Science Teaching, 35*(4), 343-353.

Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative Research: A Guide to Design and Implementation*: Wiley.

Miller, J. D., & Kimmel, L. G. (2012). Pathways to a STEMM profession. *Peabody Journal of Education, 87*(1), 26-45.

Mishra, P., Graves-Wolf, L., Cunnings-Moton, S., Seals, C., Mehta, R., Berzina, I., . . . Pawlicki, D. (2016). *Reinventing TPACK, STEM Teaching and Leadership in an Urban Context*. Paper presented at the Society for Information Technology & Teacher Education International Conference 2016, Savannah, GA.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers college record, 108*(6), 1017.

Mishra, P., & Koehler, M. J. (2008). *Introducing Technological Pedagogical Content Knowledge*. Paper presented at the Annual Meeting of the American Educational Research Association, New York City.

National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*: National Academies Press.

Owen, S. M. (2015). Teacher professional learning communities in innovative contexts:'ah hah moments','passion'and 'making a difference'for student learning. *Professional Development in Education, 41*(1), 57-74.

Patton, M. Q. (2014). *Qualitative Research & Evaluation Methods: Integrating Theory and Practice*: SAGE Publications.

Prinsley, R., & Baranyai, K. (2015). STEM skills in the workforce: what do employers want. *Office of the Chief Scientist, Canberra*.

Prinsley, R., & Johnston, E. (2015). *Transforming STEM teaching in Australian primary schools: everybody's business*. Canberra, Australia: Office of the Chief Scientist.

Pryor, C. R., & Kang, R. (2013). Project-Based Learning: An Interdisciplinary Approach for Integrating Social Studies within STEM. In R. M. Capraro, M. M. Capraro, & J. R. Morgan (Eds.), *STEM Project-Based Learning* (2nd ed.). Rotterdam, The Netherlands: Sense Publishers.

Punch, K. F. (2014). *Introduction to Social Research: Quantitative & Qualitative Approaches*. London: SAGE.

QSR International Pty Ltd. (2014). NVivo qualitative data analysis Software (Version 10).

Ramírez-Montoya, M. S. (2017). *Handbook of Research on Driving STEM Learning With Educational Technologies*: IGI Global.

Ritchie, J., Lewis, J., Nicholls, C. M. N., & Ormston, R. (2014). *Qualitative Research Practice: A Guide for Social Science Students and Researchers* (2nd ed.): SAGE Publications.

Root-Bernstein, R., & Root-Bernstein, M. (2011). From STEM to STEAM to STREAM: wRiting as an Essential Component of Science Education. Retrieved from https://www.psychologytoday.com/blog/imagine/201103/stem-steam-stream-writing-essential-component-science-education Accessed: 02-10-2017

Rosicka, C. (2016). *From concept to classroom: Translating STEM education research into practice*. Retrieved from Camberwell, Victoria: https://www.acer.org/epp/translational-research

Sanders, M. (2008). STEM, STEM education, STEMmania. *The Technology Teacher, 68*(4).

Satchwell, R. E., & Loepp, F. L. (2002). Designing and implementing an integrated mathematics, science, and technology curriculum for the middle school. *Journal of Industrial Teacher Education, 39*(3).

Schwandt, T. A. (1998). Constructivist, interpretivist approaches to human inquiry. In N. K. Denzin & Y. S. Lincoln (Eds.). Thousand Oaks: Sage Publications.

Stohlmann, M., Moore, T. J., & Roehrig, G. H. (2012). Considerations for teaching integrated STEM education. *Journal of Pre-College Engineering Education Research (J-PEER), 2*(1), 4.

Sutherland, J., & Schwaber, K. (2013). *The Scrum guide. The rules of the game.* Massachusetts: scrumguides.org.

Tedlock, B. (2003). Ethnography and ethnographic representation. In N. K. Denzin & Y. S. Lincoln (Eds.), *Strategies of Qualitative Inquiry* (2nd ed., pp. 165--213). Thousand Oaks, California.

Thomas, J. W. (2000). A review of research on project-based learning. *21st Century Learning, 1*(5).

Tytler, R., Appelbaum, P., & Swanson, D. (2015). Subject matters of science, technology, mathematics and engineering. *The SAGE guide to curriculum in education*, 27-35.

Tytler, R., Osborne, J., Williams, G., Tytler, K., & Cripps Clark, J. (2008). *Opening up pathways: Engagement in STEM across the Primary-Secondary school transition*.

Tytler, R., Symington, D., & Smith, C. (2011). A Curriculum Innovation Framework for Science, Technology and Mathematics Education. *Research in Science Education, 41*(1), 19-38. doi:10.1007/s11165-009-9144-y

Van Maanen, J. (1995). *Representation in ethnography*: Sage Publications, Inc.

Victorian Curriculum and Assessment Authority. (2017). The Victorian Curriculum F–10. Retrieved from http://victoriancurriculum.vcaa.vic.edu.au/ Accessed 12-09-17

Walker, A., & Leary, H. (2009). A problem based learning meta analysis: Differences across problem types, implementation types, disciplines, and assessment levels. *Interdisciplinary Journal of Problem-based Learning, 3*(1), 6.

Walker, A. E., Leary, H., Hmelo-Silver, C. E., & Ertmer, P. A. (2015). *Essential Readings in Problem-based Learning*: Purdue University Press.

Wiliam, D. (2011). *Embedded Formative Assessment*. Moorabbin, Victoria: Hawker Brownlow Education.

Wiliam, D., Lee, C., Harrison, C., & Black, P. (2004). Teachers developing assessment for learning: Impact on student achievement. *Assessment in Education: Principles, Policy & Practice, 11*(1), 49-65.

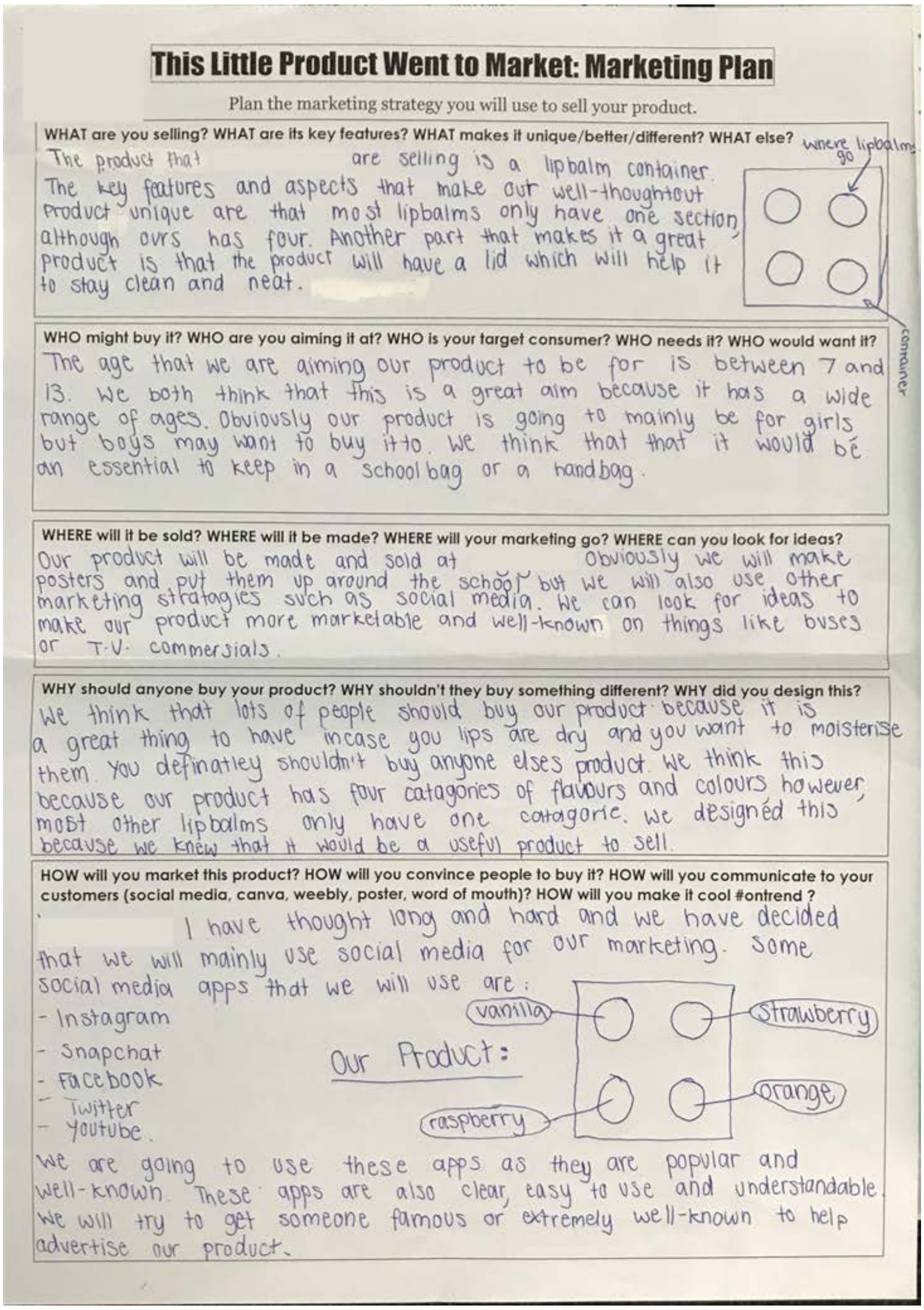
Appendices

The following section showcases a selection of the materials teacher-participants used in their STEM teaching. Some resources demonstrate their planning, others assessment, and some demonstrate the products that students produced as a result of the learning undertaken in their classrooms.

Please note, these resources are permitted for use in the context of this thesis only. No reproduction without explicit permission of the participant through contact with the researcher. aidan.cornelius-bell@flinders.edu.au

List of appendices

Appendix 1 – Henry



This Little Product Went to Market: Marketing Plan

Plan the marketing strategy you will use to sell your product.

WHAT are you selling? WHAT are its key features? WHAT makes it unique/better/different? WHAT else?

The product that are selling is a lipbalm container. The key features and aspects that make our well-thoughtout product unique are that most lipbalms only have one section although ours has four. Another part that makes it a great product is that the product will have a lid which will help it to stay clean and neat.

WHO might buy it? WHO are you aiming it at? WHO is your target consumer? WHO needs it? WHO would want it?

The age that we are aiming our product to be for is between 7 and 13. We both think that this is a great aim because it has a wide range of ages. Obviously our product is going to mainly be for girls but boys may want to buy it to. We think that that it would be an essential to keep in a school bag or a handbag.

WHERE will it be sold? WHERE will it be made? WHERE will your marketing go? WHERE can you look for ideas?

Our product will be made and sold at Obviously we will make posters and put them up around the school but we will also use other marketing stratagies such as social media. We can look for ideas to make our product more marketable and well-known on things like buses or T.V. commersials.

WHY should anyone buy your product? WHY shouldn't they buy something different? WHY did you design this?

We think that lots of people should buy our product because it is a great thing to have incase you lips are dry and you want to moisterise them. You definatley shouldn't buy anyone elses product. We think this because our product has four catagories of flavours and colours however most other lipbalms only have one catagorie. We designed this because we knew that it would be a useful product to sell.

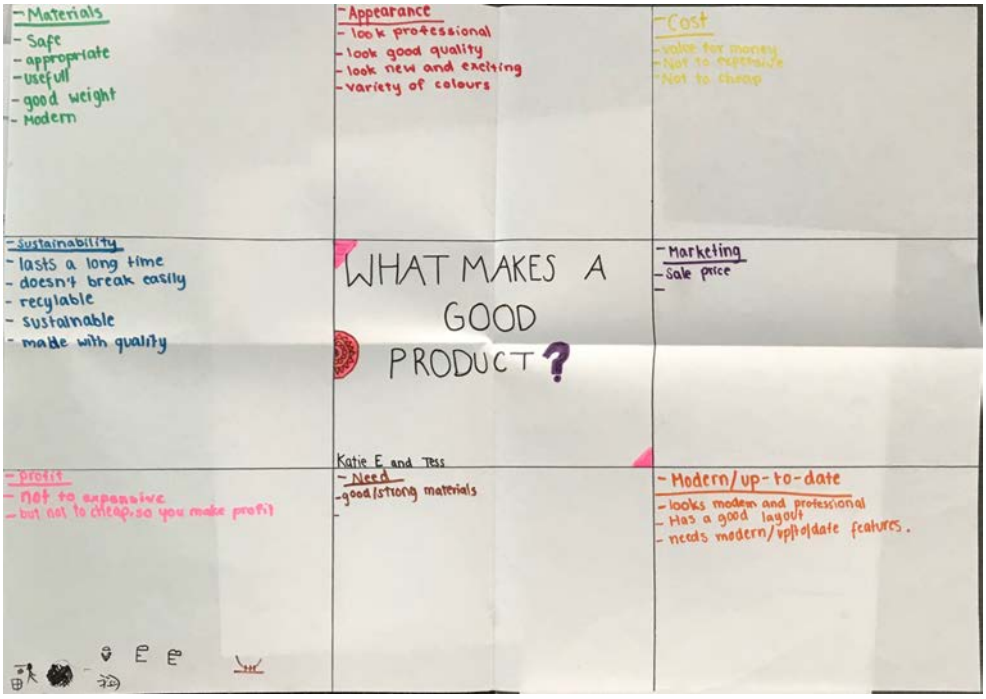
HOW will you market this product? HOW will you convince people to buy it? HOW will you communicate to your customers (social media, canva, weebly, poster, word of mouth)? HOW will you make it cool #ontrend ?

I have thought long and hard and we have decided that we will mainly use social media for our marketing. Some social media apps that we will use are:

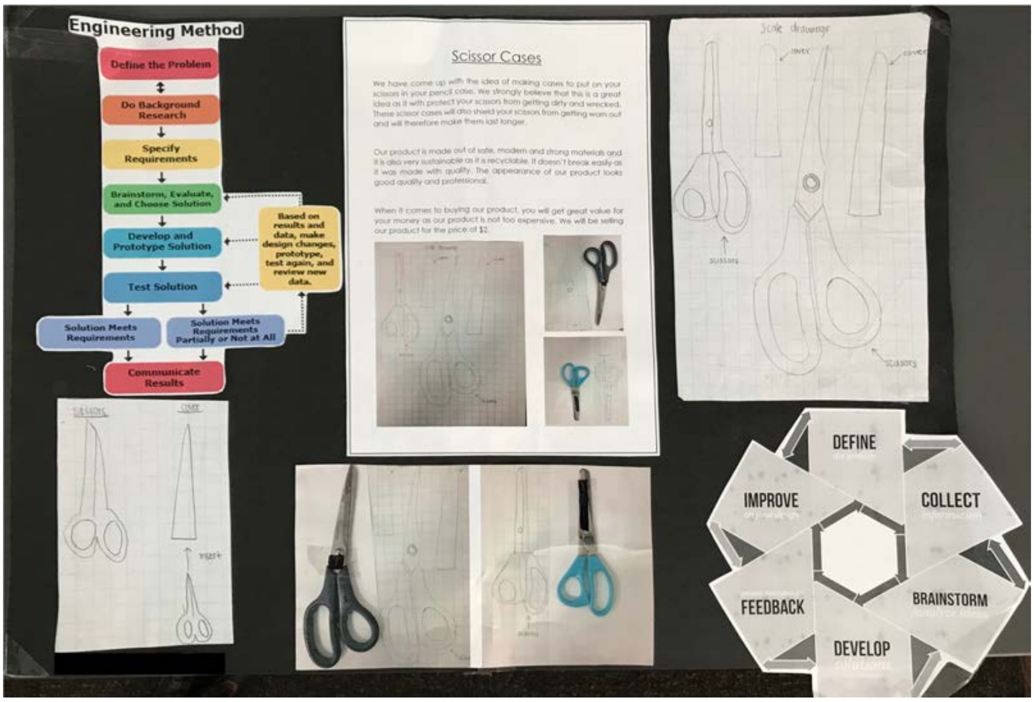
- Instagram
- Snapchat
- Facebook
- Twitter
- Youtube.

We are going to use these apps as they are popular and well-known. These apps are also clear, easy to use and understandable. We will try to get someone famous or extremely well-known to help advertise our product.

An early scaffold used in Henry's STEM Classroom to help students think about the product they were to design and eventually print on the 3D Printer.

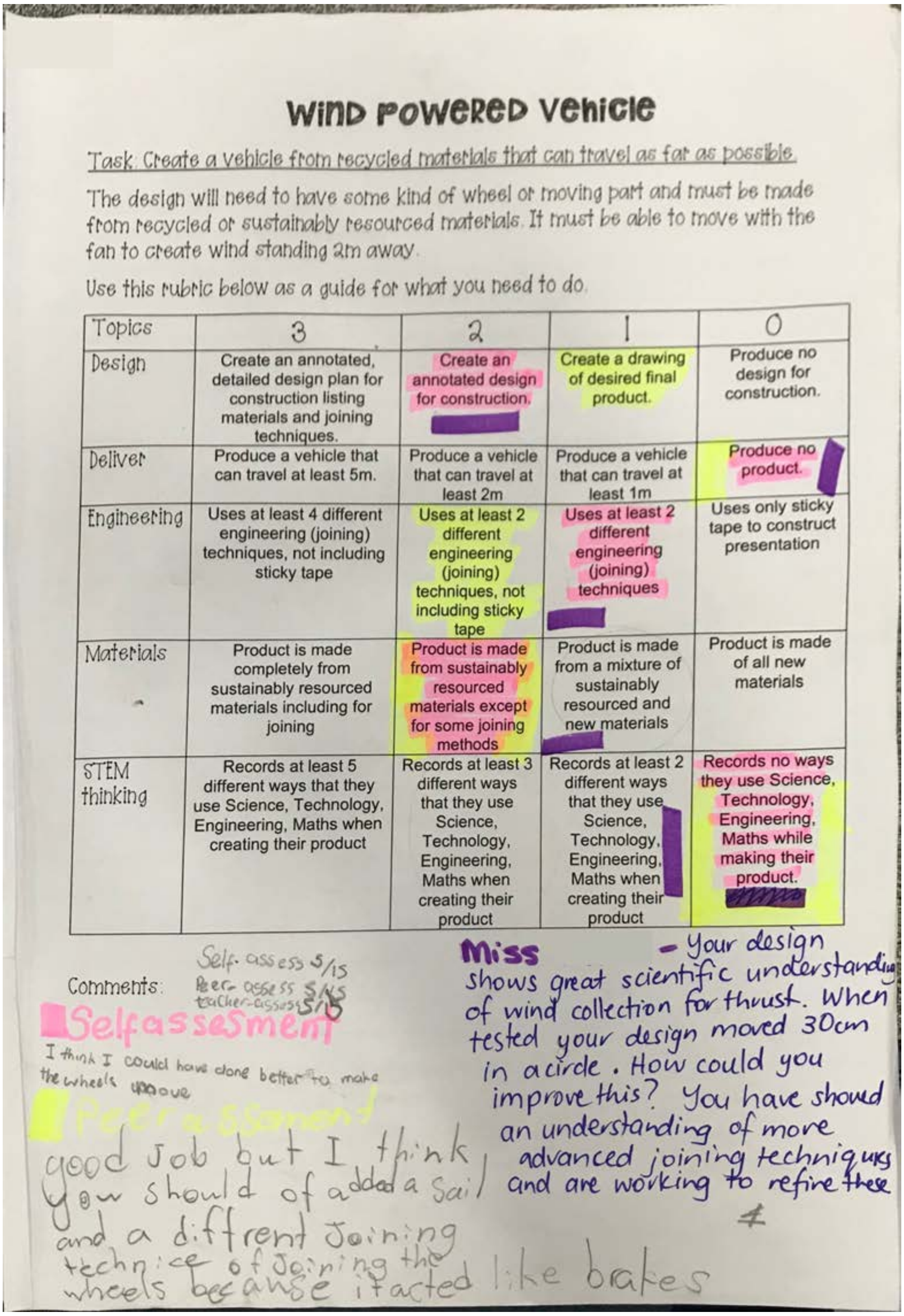


An additional early scaffold that students were encouraged to complete to demonstrate their understanding before commencing with their design of a product.



Some of the work students produced detailing their design for the 3D printer, work produced by Year 7 students in Henry's class.

Appendix 2 – Kate



WIND POWERED VEHICLE

Task: Create a vehicle from recycled materials that can travel as far as possible.

The design will need to have some kind of wheel or moving part and must be made from recycled or sustainably resourced materials. It must be able to move with the fan to create wind standing 2m away.

Use this rubric below as a guide for what you need to do.

Topics	3	2	1	0
Design	Create an annotated, detailed design plan for construction listing materials and joining techniques.	Create an annotated design for construction.	Create a drawing of desired final product.	Produce no design for construction.
Deliver	Produce a vehicle that can travel at least 5m.	Produce a vehicle that can travel at least 2m	Produce a vehicle that can travel at least 1m	Produce no product.
Engineering	Uses at least 4 different engineering (joining) techniques, not including sticky tape	Uses at least 2 different engineering (joining) techniques, not including sticky tape	Uses at least 2 different engineering (joining) techniques	Uses only sticky tape to construct presentation
Materials	Product is made completely from sustainably resourced materials including for joining	Product is made from sustainably resourced materials except for some joining methods	Product is made from a mixture of sustainably resourced and new materials	Product is made of all new materials
STEM thinking	Records at least 5 different ways that they use Science, Technology, Engineering, Maths when creating their product	Records at least 3 different ways that they use Science, Technology, Engineering, Maths when creating their product	Records at least 2 different ways that they use Science, Technology, Engineering, Maths when creating their product	Records no ways they use Science, Technology, Engineering, Maths while making their product.

Comments: Self-assess 5/15 Peer-assess 5/15 teacher-assess 5/15

Selfassesment

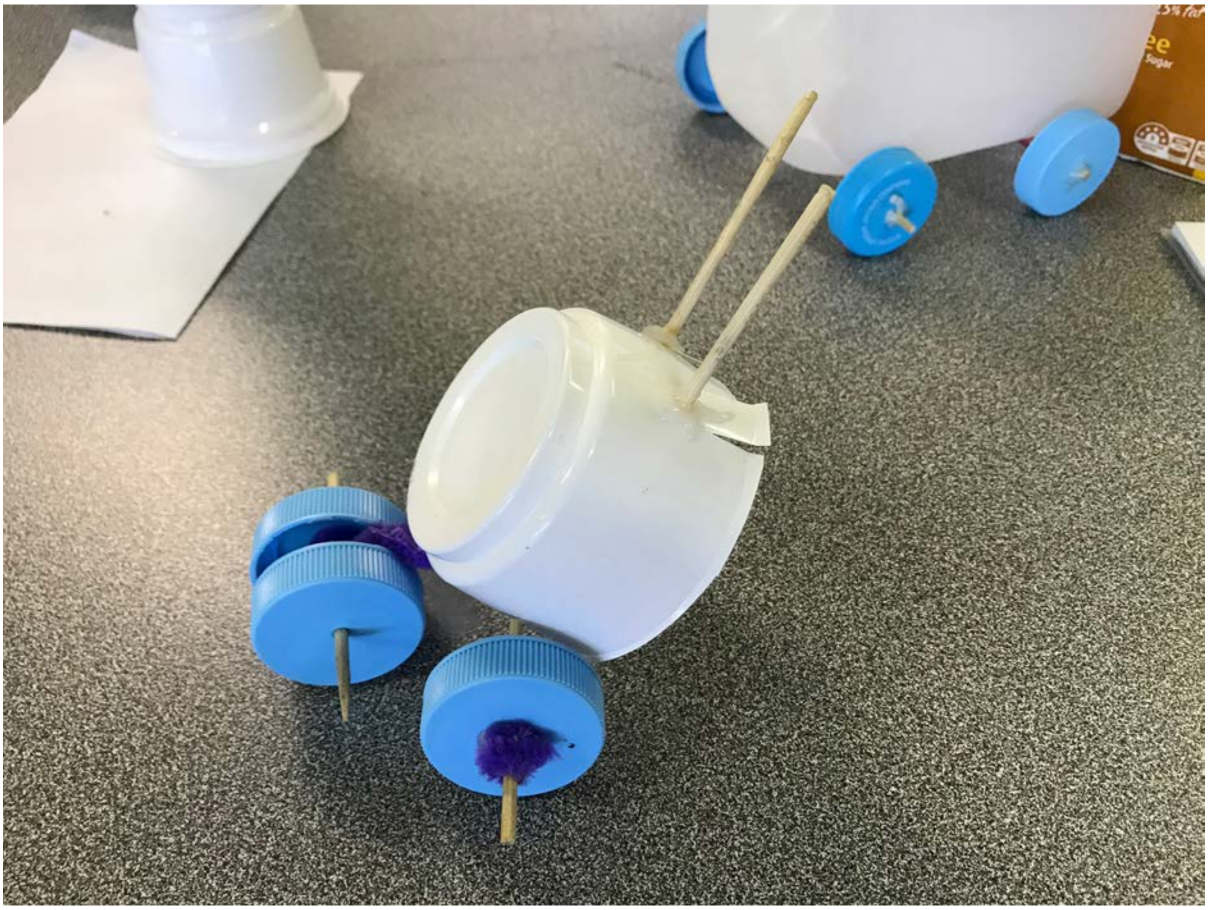
I think I could have done better to make the wheels move

Peer assesment

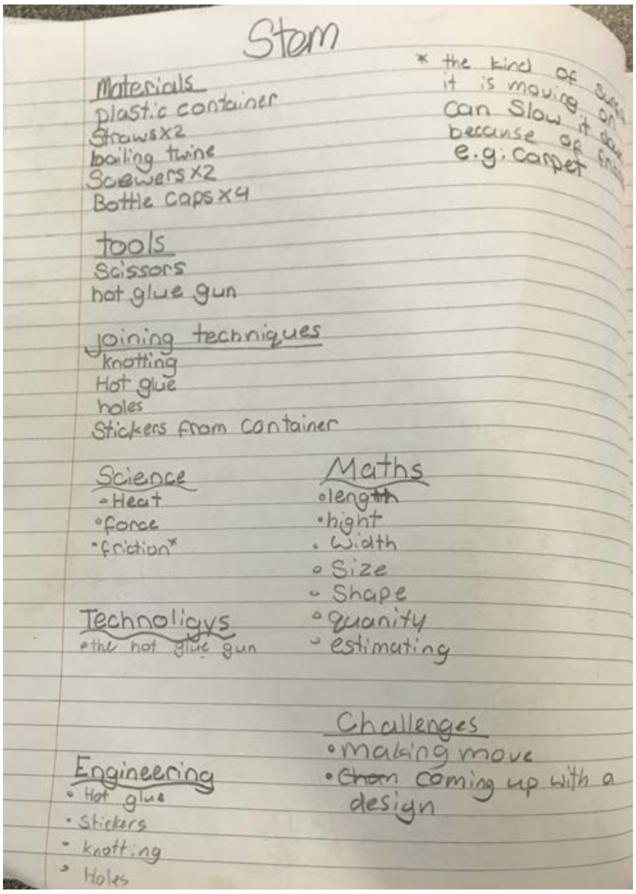
good Job but I think you should of added a sail and a diffrent Joining technice of Joining the wheels because it acted like brakes

Miss – Your design shows great scientific understanding of wind collection for thrust. When tested your design moved 30cm in a circle. How could you improve this? You have showed an understanding of more advanced joining techniques and are working to refine these

An example of an assessment of students: self, peer, and teacher assessment and feedback shown. This project sheet also constituted the design brief for students.



An example product produced by students in Kate’s classroom. This project drew on the science curriculum for forces, and culminated in a design-and-technology focussed production.



An example of the brainstorming activities students are asked to undertake in Kate's classroom before they commence their production.

Appendix 3 – Rosa

Year 5/6 Integrated Curriculum Planner Term 3 2017
Areas of Study – STEM
Planning for the investigation

What do we want the students to know by the end of the unit?

(Content Knowledge and Understandings - expectations in the curriculum, learning descriptors translated)

CIVICS AND CITIZENSHIP

- Identify who can be an Australian citizen and describe the rights, responsibilities and shared values of Australian citizenship and explore ways citizens can participate in society (VCCCC014)
- Identify different points of view on a contemporary issue relating to democracy and citizenship(VCCCC015)
- Investigate how people with shared beliefs and values work together to achieve their goals and plan for action(VCCCC016)
- Examine the concept of global citizenship(VCCCC017)

SCIENCE

BIOLOGICAL SCIENCE

- The growth and survival of living things are affected by the physical conditions of their environment (VCSSU075)
  - investigating how changing the physical conditions for plants impacts on their growth and survival, for example, changing salt water concentrations, using fertilisers or transferring to a different soil type
  - researching organisms that live in extreme environments, for example, Antarctica, a desert or deep sea

CHEMICAL SCIENCE

- Changes to materials can be reversible, including melting, freezing, evaporating, or irreversible, including burning and rusting (VCSSU077)
  - investigating the three changes of state in water

SCIENCE INQUIRY SKILLS

QUESTIONING AND PREDICTING

- With guidance, pose questions to clarify practical problems or inform a scientific investigation, and predict what the findings of an investigation might be based on previous experiences or general rules(VCSIS082)

PLANNING AND CONDUCTING

- With guidance, plan appropriate investigation types to answer questions or solve problems and use equipment, technologies and materials safely, identifying potential risks (VCSIS083)
- Decide which variables should be changed, measured and controlled in fair tests and accurately observe, measure and record data (VCSIS084)

RECORDING AND PROCESSING

- Construct and use a range of representations, including tables and graphs, to record, represent and describe observations, patterns or relationships in data (VCSIS085)

ANALYSING AND EVALUATING

- Compare data with predictions and use as evidence in developing explanations (VCSIS086)
- Suggest improvements to the methods used to investigate a question or solve a problem (VCSIS087)

COMMUNICATING

- Communicate ideas and processes using evidence to develop explanations of events and phenomena and to identify simple cause-and-effect relationships(VCSIS088)

What does that mean?

Critically examining technologies that are used regularly in the home and in local, national, regional or global communities, with consideration of society, ethics and social and environmental sustainability factors. Students consider why and for whom technologies were developed.

Exploring how design and technologies and the people working in a range of technologies contexts contribute to society. They seek to explore innovation and establish their own design capabilities. Students are given new opportunities for clarifying their thinking, creativity, analysis, problem-solving and decision-making. They explore trends and data to imagine what the future will be like and suggest design decisions that contribute positively to preferred futures.

.

What will they be able to make, say, write or do to demonstrate this?

Skills:

Students work to identify and sequence steps needed for a design task. They negotiate and develop plans to complete design tasks, and follow plans to complete design tasks safely, making adjustments to plans when necessary. Students identify, plan and maintain safety standards and practices when creating designed solutions.

ETHICAL CAPABILITY

Understanding concepts:

- Examine the contested meaning of concepts including truth and happiness and the extent to which these concepts are and should be valued (VCECU009)
- Discuss how ethical principles can be used as the basis for action, considering the influence of cultural norms, religion, worldviews and philosophical thought on these principles (VCECU010)
- Examine how problems may contain more than one ethical issue (VCECU011)

Decision making and actions:

- Explore the significance of 'means versus ends' by considering two ways to act when presented with a problem: one that privileges means and one ends(VCECD012)
- Discuss the role and significance of conscience and reasoning in ethical decision-making (VCECD013)

CRITICAL AND CREATIVE THINKING

- Examine how different kinds of questions can be used to identify and clarify information, ideas and possibilities (VCCCTQ021)
- Experiment with alternative ideas and actions by setting preconceptions to one side (VCCCTQ022)
- Consider the importance of giving reasons and evidence and how the strength of these can be evaluated (VCCCTR025)
- Consider when analogies might be used in expressing a point of view and how they should be expressed and evaluated (VCCCTR026)
- Examine the difference between valid and sound arguments and between inductive and deductive reasoning, and their degrees of certainty(VCCCTR027)

DESIGN & TECHNOLOGY

- Investigate how people in design and technologies occupations address competing considerations, including sustainability, in the design of solutions for current and future use (VCDSTS033)
- Investigate characteristics and properties of a range of materials, systems, components, tools and equipment and evaluate the impact of their use (VCDSTC037)
- Critique needs or opportunities for designing, and investigate materials, components, tools, equipment and processes to achieve intended designed solutions(VCDSCD038)
- Generate, develop, communicate and document design ideas and processes for audiences using appropriate technical terms and graphical representation techniques (VCDSCD039)
- Apply safe procedures when using a variety of materials, components, tools, equipment and techniques to produce designed solutions(VCDSCD040)
- Negotiate criteria for success that include consideration of environmental and social sustainability to evaluate design ideas, processes and solutions (VCDSCD041)
- Develop project plans that include consideration of resources when making designed solutions(VCDSCD042)

Why are we doing this? At this age, time in their lives, developmental level, in this community and culture. How will my learners use this knowledge and these understandings to make a difference in their lives and the lives of others?	**How can we help achieve the global goals relating to water?** **How can we use STEM to produce an object that meets the needs of global goals involving water?**

What can we design to impact a water related problem?

What skills will they need to be able to do this? What else will they need to know? -prerequisite knowledge, how will it need to develop?	Tools needed to make your product - ● Tangible ● Conducting experiments and investigations ● Design Thinking process	Working in teams of 3 ● Low 3's and high 3's ● Enabling Group - Water samples/Merri Creek/CERES/Solar water wheel	https://designthinkingforeducators.com/ http://www.notosh.com/design-thinking

Week	Curriculum Knowledge, understanding /Skills/I can….	Tasks and Teaching Strategies	Resources	Assessment tasks (make, say, write or do)
1 S C I E N C E	**Questioning and Predicting** With guidance, pose questions to clarify practical problems or inform a scientific investigation, and predict what the findings of an investigation might be based on previous experiences or general rules(VCSIS082) **Biological Science** The growth and survival of living things are affected by the physical conditions of their environment (VCSSU075)	Goal 6 - UN Targets; have a positive influence on one of the UN goal 6 targets. Water - problems faced with water BIOLOGICAL THEME Workshop 1: What is an experiment? Valid and fair testing Workshop 2: What is science? (in terms of what we know about water) Workshop 3: Hypothesis/Scientific methods (importance of making predictions and testing) EXPERIMENT "The Power of Water" (Surface tension) *Raft Building* Engage: Explore: Explain: Elaborate: Evaluate:	Raft races *https://www.youtube.com/watch?v=1NpS899_e10* Then as an explanation https://www.youtube.com/watch?v=Gpcv9QT0KpA Toothpaste Honey Jam Shaving cream	Cross poll book - Definitions of ● Science ● Experiment ● Scientific methods Primary Connections investigation template https://drive.google.com/open?id=0B4AiJVw6gBdKUUFHendZcktBMU0
2 S C I E N C E	**Planning and Conducting** With guidance, plan appropriate investigation types to answer questions or solve problems and use equipment, technologies and materials safely, identifying potential risks (VCSIS083) Decide which variables should be changed, measured and controlled in fair tests and accurately observe, measure and record data (VCSIS084) **Recording and Analysing** Construct and use a range of representations, including tables and graphs, to record, represent and describe observations, patterns or relationships in data (VCSIS085) **Chemical Science**	CHEMICAL THEME Workshop 1: Planning and conducting an experiment - Primary Connections Grade 6 Change Detectives p84 Workshop 2: Recording observations (results from last week's experiment) How to construct and use a graph - Primary Connections Grade 6 Change Detectives p81 Workshop 3: What is water - Three states EXPERIMENT Can you taste the difference between tap and bottled water? Possible Experiment- Does the taste of water change when it is coloured? (Using food dye to trick the brain into perceiving different tastes).	Evaporation experiment http://www.rookieparenting.com/evaporation-distillation-water-science/ The 3 states of water: http://easyscienceforkids.com/all-about-states-of-matter/ http://idahoptv.org/sciencetrek/topics/matter/facts.cfm Monitoring of Goal 6 (Water and Sanitation) http://www.sdg6monitoring.org/news?category=Indicators	Cross poll book - ● Requirements for conducting an experiment ● Recording observations ● Explain 3 states of water Primary Connections investigation template

The previous three pages are an example of the integrated PBL unit plan that Rosa prepares with her co-teachers for a term of work. Snipped for privacy and length.

CRITICAL THINKING RUBRIC				
Critical Thinking Opportunity at Phases of a Project	Below Standard 😐 •	Getting There 😊 •	At Standard 😬 •	Above Standard • 💪 •
Launching the Project: **Analyze Driving Question and Begin Inquiry**	❑ I cannot explain what I would need to know to be able to answer the Driving Question ❑ I still need to learn how another person might think differently about the Driving Question ❑ I still need to learn how to ask questions about what our audience or product users might want or need	❑ I can identify a few things I would need to know to be able to answer the Driving Question ❑ I can understand that another person might think differently about the Driving Question ❑ I can ask a few questions about what our audience or product users might want or need	❑ I can explain what I would need to know to be able to answer the Driving Question ❑ I can explain how different people might think about the Driving Question ❑ I can ask lots of questions about what our audience or product users might want or need	
Building Knowledge, Understanding, and Skills: **Gather and Evaluate Information**	❑ I still need to learn how to use information from different sources to help answer the Driving Question ❑ I still need to learn how to think about whether my information is relevant or if I have enough	❑ I can use information from different sources to help answer the Driving Question, but I may have trouble putting it together ❑ I can think about whether my information is relevant and if I have enough, but I don't always decide carefully	❑ I can use information from different sources to help answer the Driving Question ❑ I can decide if my information is relevant and if I have enough	
Developing and Revising Ideas and Products: **Use Evidence and Criteria**	❑ I still need to learn how to identify the reasons and evidence an author or speaker uses to support a point ❑ I still need to learn how to decide if an idea for a product or an answer to the Driving Question is a good one ❑ I still need to learn how to use feedback from other students and adults to improve my writing or my design for a product	❑ I can identify some of the reasons and evidence an author or speaker uses to support a point ❑ I can tell when an idea for a product or an answer to the Driving Question is a good one, but cannot always say why ❑ I can sometimes use feedback from other students and adults to improve my writing or my design for a product	❑ I can explain how an author or speaker uses reasons and evidence to support a point that helps me answer the Driving Question ❑ I can explain how to decide if an idea for a product or an answer to the Driving Question is a good one ❑ I can use feedback from other students and adults to improve my writing or my design for a product	
Presenting Products and Answers to Driving Question: **Justify Choices**	❑ I still need to learn how to explain my ideas in an order that makes sense ❑ I still need to learn how to use appropriate facts or relevant details to support my ideas	❑ I can explain my ideas, but some might be in the wrong order ❑ I can use some facts and details to support my ideas, but they are not always appropriate and relevant	❑ I can explain my ideas in an order that makes sense ❑ I can use appropriate facts and relevant details to support my ideas	

The previous is an example of one of the rubrics Rosa uses throughout the term to assess students' critical thinking.

WATER

How can we help achieve the global goals relating to water?

Goal 6 - Clean water and Sanitation
Goal 13- Climate Action
Goal 14 - Life Below water

Some specific targets include:

- Ensure all have access to safe water.
- Ensure all have access to sanitation (safe sewage disposal and good waste management) and public education on healthy hygiene habits.
- Monitor water quality to reduce contamination. Prevent chemicals or contaminants from being thrown into the water.
- Improve water use, developing greater resources for its reuse.
- Help people and communities understand how they can improve their own water management and sanitation.
- Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.
- Reduce marine pollution by 2025, since much of the pollution comes from human activities on land.
- Help bring change that will slow illegal fishing, overfishing, and other destructive fishing practices.
- Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels
- By 2020, conserve at least 10 per cent of coastal and marine areas.
- Ensure people are well prepared for hazards related to climate and natural disasters.
- Help fight climate change issues by involving local communities and governments.

DESIGN CHALLENGE

It is your task to design an end product that could help to achieve one of these targets.
Your end product will be exhibited during a large scale public exhibition night.
Your end product should aim to be a physical product or experiment built with your knowledge of Science, Technology, Engineering and Maths.

CHALLENGE

Science - Share what you tested and measured.
- Scientific method
- Science inquiry questions

Technology - Project plans, sketches, notes.
- What is the problem or need?
- Who has this problem or need?
- Why is it important to solve?

Engineering - What materials did you use and why?
- empathy in design
- extreme affordability of the engineering solution
- ease of use of the engineering solution
- reliability or dependability of the engineering solution
- careful and thoughtful analysis of a problem
- Teamwork
- setting and accomplishing important goals

Maths - What data did you gather and how does it help your project?
- How did you use scale and/or ratio?
- What kind of measurement did you learn/use?

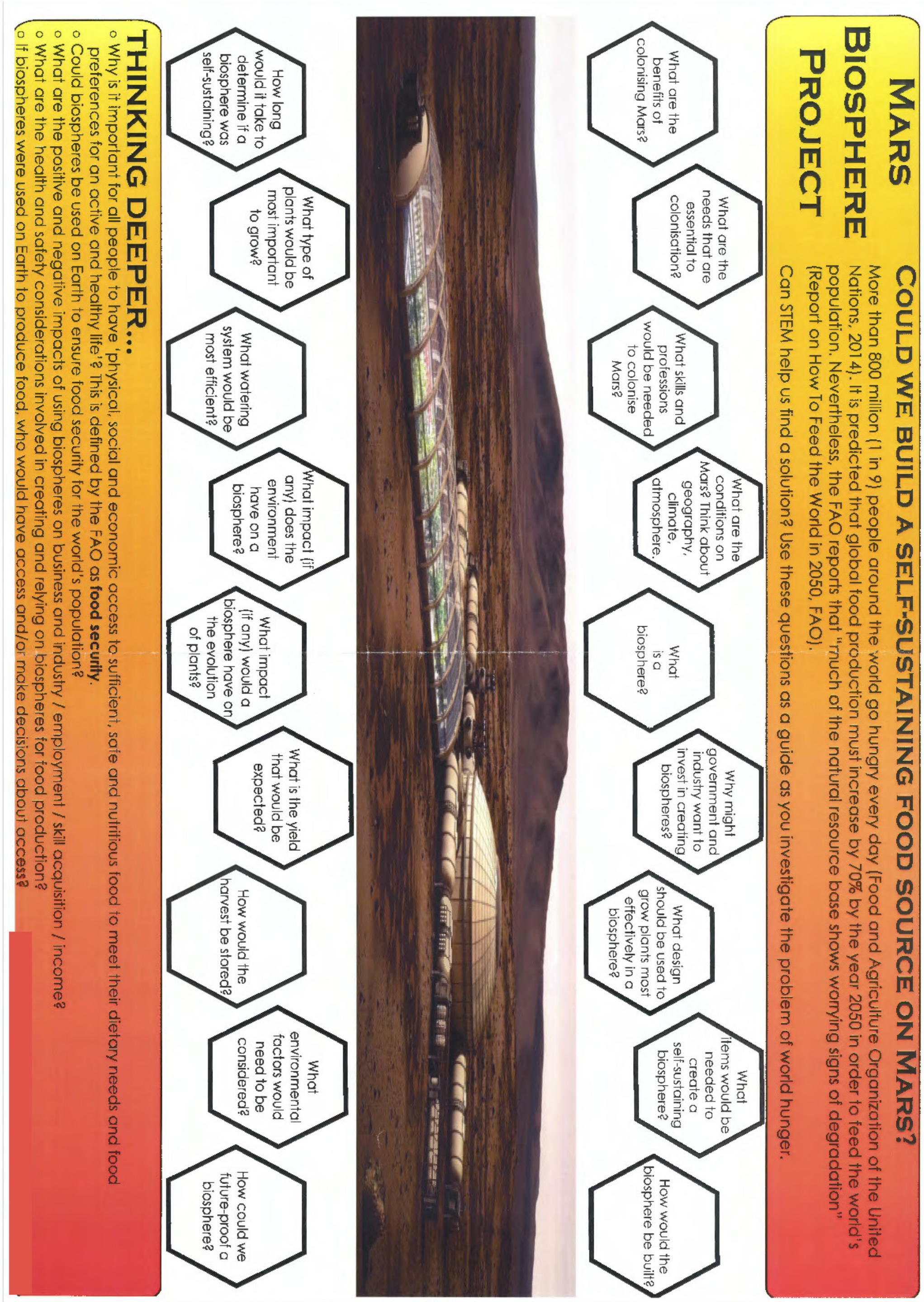
What CAN YOU USE?

Some resources to help you along the way:

Plastic in waterways	https://water.org/ http://yarraandbay.vic.gov.au/issues/litter http://www.epa.vic.gov.au/your-environment/water https://www.theoceancleanup.com/

The previous are examples of the project brief students are provided when they commence the unit of work above.

Appendix 4 – Stephanie



An example of the project brief Stephanie uses when commencing units of work in her classroom. Notable, the questions asked of students based on Australian Curriculum content descriptions.

Choosing Groups. **Week 10, Term 1**

After the talk Ms [redacted] said that we should start think about groups. I didn't think much of it.

A few days later, Ms [redacted] told my class and I that we had to chose our groups. [redacted], [redacted] and I all agreed to become one group. I wanted to make a good choice about who I was with. I decided my group would be perfect. Some of my other friends were already in a group anyway. [redacted] and I were going to work together. We needed one more person for our group. A few days went by. [redacted] and I still didn't have our group. We weren't the only ones though. There were still lots of of people that were not 100% sure on their groups. [redacted] and I decided to talk to [redacted] and see if she wanted to work with us. She said that she was kind of already in a group with two other people. I think she had already done a little bit of research with them or told them some good websites. [redacted] said she still wanted to work with as though. I was quite surprised by this because I thought she would want to stay with who she was kind of already working with. The other people she had planned on working with and did a little bit of work with didn't mind. I was so happy with my group and couldn't wait to start working with them on the Mars Biosphere Project!

An example of a students' reflection in a *Google Doc* about the learning that had been taking place in their classroom. Students contributed to these documents each week and were assessed on the knowledge and skills demonstrated within.

Appendix 5 – Interview Guides

What follows is the interview guide for the initial interview. Note the interviews were semi-structured and were subject to deviation from this guide.

1. Where did you begin your teaching career, and how did it lead to you teaching STEM?
2. Was there a stimulus to start this unit of work or lesson sequence?
3. Can you tell me about how you approach the planning of curriculum?
4. How did you decide which parts of the curriculum to link to with this sequence?
5. Can you tell me about the pedagogical approach behind this unit or lesson sequence?
6. Was ICT a consideration in your planning?
7. What evidence do you look for from students to demonstrate their STEM learning?
8. What are the challenges around assessment and recording students' learning progress?

What follows is the follow up interview guide. Note the interviews were semi-structured and were subject to deviation from this guide.

1. Tell me about this student's work…
2. What was your vision for how students would apply their learning to creatively produce this work?
    a. How did you support the student(s) to achieve this vision/product?
    b. Did the student(s) direct the conception of the vision/product?
3. What was the relationship between developing concepts and applying them in the work sample?
    a. Was there a design brief?
4. How did you assess this student's work?
    a. How did the student demonstrate their conceptual understanding?
    b. How did the student demonstrate their development of skills?
5. Did this learning meet/exceed your vision for this unit of work?
6. What feedback did you provide to this student?
    a. Were opportunities available for the student to revisit/revise the work over the course of its production before a final submission or grade was given?
7. If you were to do this (kind of) unit again, what would you do differently?
8. What is the next step in your STEM teaching journey?

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