The Value of Me in STEAM: Teacher identity development through STEAM education

by Melissa Silk

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Doctor of Philosophy

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Certificate of Original Authorship

I, Melissa Silk declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of International Studies and Education, Faculty of Arts and Social Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

In a profession enmeshed with theoretical, intellectual, and emotional complexities, asking secondary subject specialist educators to teach outside a comfort zone of words, equations, practice and expertise, is risky. This research presents a range of case studies of how teachers took such risks in the context of STEAM education, with a view to reinvigorating and effecting innovative pedagogy integrating science, technology, engineering, the arts, and mathematics. Four case studies were conducted over two years from three schools' professional learning (PL) programs and one professional organisation. The total number of participants was 58, with intensive focus on 14 teachers. Weaving a complex web of interpretation based on the dual framework of phenomenography and social constructivism, the research investigates two questions: (1) How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?; and (2) How does experiencing activity emotions in STEAM projects enhance or detract from the teachers' personal identity development? On the question of effecting teacher transformation, results from mixed methods data collection, including experience sampling, demonstrated the influence of dialectical emotions experienced during STEAM learning. Such emotions encouraged shifts in teachers' self-perception and identity as STEAM challenges were accepted, enacted and overcome. Divergence from solid subject specific knowledge, in the interest of considering pedagogical alternatives to conventional practice, afforded teachers new capabilities related to ways of knowing, being and becoming. Evidence of small and large teacher transformations emerged through the expression and experience of STEAM transdisciplinarity, teachers' activity emotions, and a new sense of teacher purpose related to the impact of STEAM. This gives rise to a key recommendation: that designing STEAM PL expects to encounter a range of teachers unfamiliar with transdisciplinary challenge, but that each type of teacher brings their own value to the learning. To develop a full picture of the value of STEAM for non-generalist teachers, additional studies will be needed to ascertain how authentic transdisciplinary STEAM encourages teachers to view their own knowledge through different lenses, potentially viewing themselves in alternative ways. This study,

however, indicates how a treasury of unique STEAM ideas put into practice *can* be personally and professionally transformative for teachers, even for just a short time.

Figure A.1: Teacher research participants engaging in STEAM learning and teaching.

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Chapter One – Introduction

If someone had told Mallory that he would climb Everest but die in the attempt, still he would have climbed it. (Winterson, 2001, p. 150)

A key aspect of this research points to the importance of considering teacher transformation through experiences in STEAM professional learning (PL), in which the appreciation of the dynamic contribution of teacher emotions is measured. STEM represents integrated science, technology, engineering and mathematics, and central to the arts are the key learning areas of humanities, language arts, dance, drama, music, visual arts, design and new media. This research investigates how blending and embedding the arts in STEM to generate the fusion acronym of STEAM, is a powerful method of enacting authentic transdisciplinary learning for teachers as well as students. For conventional teachers, such fusion creates divergence from solid subject specific knowledge, and may lead to new ways of understanding STEM concepts as well as developing novel creative approaches to visualising, enacting or embodying such concepts. For secondary education in particular, transdisciplinary learning expects secondary teachers to incorporate relational understandings in the subjects they teach, as a means to challenge convention. This sees the concept of transdisciplinarity as challenging the familiar and widely expected approaches to teaching and learning. STEAM asks teachers to step outside the comfort of personal and professional traits, irrespective of the practice of teaching remaining siloed and bound by seemingly rigid curriculum parameters. Hence, teachers participating in STEAM learning might experience heightened emotions when operating in unfamiliar knowledge or skill territory. This research shows that it is within these intense learning moments that STEAM has transformative capacity.

Transformative learning, according to Taylor (2016), is based on five interconnected ways of knowing: "cultural self-knowing, relational knowing, critical knowing, visionary and ethical knowing, knowing in action" (p. 92). Combined, each transcend perceived discipline boundaries and integrate disparate practices, which comes as no surprise to Root-Bernstein (2019) who advocates innovation is the result of taking "transdisciplinary leaps of imagination" by training scientists, technologists, engineers and mathematicians "in and with the arts" (p. 11). There is a growing body of literature that recognises the importance of incorporating the arts in science, technology, engineering and mathematics (STEM), being crucial for developing 'tools for thinking', as Root-Bernstein suggests. "These consist essentially of observing, imaging, abstracting, patterning, analogizing, empathizing, dimensional thinking, modeling, playing, transforming and synthesizing" (p. 10). For teachers, it may be impossible to put such tools to use without also experiencing emotions.

My study has found that learning through STEAM exposes key opportunities for teachers to blend tricky outlaw emotions such as fear, anxiety and resistance, with the activity emotions of joy, elation, wonder and awe. Such discoveries are elucidated in discussion of how the participating teachers were encouraged to employ STEAM learning as a conduit to knowing, imagining, creating, and innovating while indirectly experiencing moments of wonderment and awe. Robinson (2010) describes such moments as an aesthetic experience. Certainly, in this research, teachers participating in STEAM learning encountered a series of cumulative experiences replete with dialectical emotional responses. The main challenge of the research was to harness teachers' emotions and employ them as tools for the indispensable divergent and convergent thinking that underpins STEAM's transdisciplinarity. If convergence can be described as a meeting or agreement of opinions and actions, occurring at a specific point or degree, it appears that the synthesis forming STEAM from STEM acknowledges the divergent inclusion of the Arts as the first step to innovating knowledge building in STEM.

1.1 Background to this research

Amidst the revelations of education statistics and Government innovation agendas related to Australian STEM industries, I find it is easy to be overwhelmed by the problem of increasing uptake in STEM, starting with teaching and learning priorities in schools. However, I find it just as easy to align my research motivation with a similar goal, due to many professional conversations related to the issue of how to measure secondary school STEM uptake within the flurry of media and political activity promoting the sad statistics of poor engagement. My research is not concerned with assessing the plethora of existing STEM or STEAM resources, or finding exemplar teachers already operating in connected cultures of thinking. Rather, it examines the way in which the participating teachers responded to unique methods of STEAM learning and teaching, co-created specifically for my research. What I have found throughout the process of researching this topic is that even the smallest attempt to reconcile the problem of siloed approaches to learning, is a reminder that transdisciplinary STEAM experiences designed in collaboration with likeminded educators represent a valid contribution to educational change. The participating teachers in my research have demonstrated that for them, the value of STEAM may simply be an appreciation of the possibilities of exploring STEM concepts, particularly mathematical concepts, through playing around with ideas, with materials, and with other people, in order to generate novel and memorable learning experiences.

Drawing on play and curiosity inherent in STEAM learning, it is important to acknowledge that both have been considered crucial to creative and innovative knowledge construction in various education contexts (Craft, 2015; Robinson, 2001; Wagner, 2012). Thus, engagement with play and curiosity from a transdisciplinary perspective manifests more in the realm of experiential connected education across disciplines, than solely situated in the arts. The types of playful pedagogical connections presented in my research demonstrate how STEAM learning for teachers, requires commitment to the formation of experiences that avoid disconnectedness, while simultaneously ensuring that the purpose or result of the experiences have relevance in terms of application to the real world. Recent education reports such as *NSW Government response to the NSW Curriculum Review – final report* (2020), *Through Growth to Achievement: Report of the Review to Achieve Educational Excellence in Australian Schools* (Gonski, D., Arcus, T., Boston, K., Gould, V., Johnson, W., O'Brien, L., . . . Roberts, M., 2018), and *Challenges in STEM Learning in Australian Schools* (Timms, Moyle, Weldon, & Mitchell, 2018), express the need to engage young people in STEM in order to increase the uptake of STEM related tertiary studies that lead to employment in STEM related industries. Interestingly and simultaneously, former New South Wales (NSW) Chief Scientist, Mary O'Kane (2018), interviewed for the Sydney Morning Herald article entitled "STEM debate has become 'misguided'" (Smith, 2018),
welcomed then NSW Education Minister, Rob Stokes' comments espousing preference for STEM at the expense of the Arts as "demonstrably ludicrous" (Smith, 2018, Para 2). Such conflicting views continue to fuel the debate about STEM + A connected curricula.

More detailed explanation of these is presented within the literature review in chapter two of this thesis.

1.1.1 STEM to STEAM Zeitgeist

The recent hype surrounding STEM to STEAM concepts in Australian education, industry and the general community can be partly attributed to the release of the National STEM School Education Strategy (2015), National Science and Innovation Agenda (*National Innovation and Science Agenda*, 2016), Australia's STEM Workforce Report (2016) and other reports such as the Australian Council for Education Research *Challenges in STEM Learning in Australian Schools* (Timms et al., 2018). At the time of the release of these reports, I was employed as a teacher in the role of 'STEAM Innovator' at an inner-city independent school in Sydney, Australia. My pedagogical commitment to learning more about STEAM afforded me many opportunities to enact, collaborate and share the learning with peers and students at that school. Moving into a research role encouraged me to distribute the profit of my STEAM learning from a well-resourced educational institution, with those not so well resourced in my educational network. I consider incentivising STEM to STEAM transdisiciplinary learning as imperative and should not restricted to privileged learning situations. Teaching across faculties at the University of Technology, including teaching into the Bachelor degree of Creative Intelligence and Innovation, allowed me to gain more understanding of how transdisciplinary models of learning could facilitate movement warranted by the growing awareness of the need for increased uptake in STEM at secondary, tertiary and industry levels. The challenge for me was how to remain engaged with the STEM/STEAM zeitgeist while not restricting myself to the creation and delivery of innovative STEAM programming at a single school alone. Each aforementioned report broadcasts the alarming statistics related to the uptake of STEM subjects in secondary and tertiary education and the on-flow effects on recruitment in STEM industries. As a result, schools have been prioritising STEM learning in an attempt to address the uptake problem. Similarly, the emergence of a range of learning organisations developing and marketing STEM/STEAM learning programs to schools and communities has significantly increased.

Such reports consistently recommend energising the teaching of science and technology, prioritising innovation, recruitment and retainment of quality teachers by collaboratively planning and strengthening teacher professional development. More recently, new curriculum implementation support for teachers, outlined in the *NSW Government's report on NSW Curriculum Review* (2020), echoed similar needs, recommending strengthened training for pre-service and in-service teachers, including monitoring the entry standards for STEM teacher education courses. *Innovation and Science Australia* (2017) reports that in comparison with international counterparts, Australian teachers engage, on average, with four days less than the reported 15 days of professional training per year. This report also questions the quality of the Australian professional development programs: "Only half of Australian teachers attending professional development programs report a moderate or large change in their day-to-day teaching as a result of the programs" (Ferris, 2017, p. 28).

As such reports filter down through Government, industry, societal systems and education, the stakeholders on the ground are obliged to engage with the inherent directives. In *The Age of STEM,* Freeman (2015) noted "Unlike several other countries, the Australian teaching landscape equates 'teaching quality' with 'teacher quality' leading to some pressure to foreground accountability regimes at the expense of professional learning" (p. 185). There are two distinct problems emerging from these reports in respect to teacher PL. The first is the perceived need for increased discipline specific training, and the second is that training in current PL contexts, has little influence on teacher development. Therein lies an ambiguity, tested in a key point made by the Organisation for Economic Co-operation and Development (OECD): "To remain competitive, workers will need to acquire new skills continually, which requires flexibility, a positive attitude towards lifelong learning and curiosity" (OECD, 2019, p. 8). This ambiguity is further explored in the literature view in chapter 2.

Previous research has established that synergetic curriculum content inspires authentic cross-disciplinary fertilisation, encouraging curiosity, experimentation and risk-taking, thus engendering key dispositions of divergent thinking (McAuliffe, 2016). Diverting teacher PL away from traditional practices and methods, by designing the learning with innovative STEAM challenge in mind, addresses the creative and imaginative inputs to learning STEM. STEAM alone does not communicate successful integrated learning and teaching to local and global audiences; however, it *is* a point of departure for divergent thinking, a launch pad for identifying and acknowledging the range of skills to be learnt to navigate through this century and beyond.

Transdisciplinarity in itself, is not new. Some teachers have been integrating subject content for their entire careers. They are valuable assets to the education system and provide solid mentorship to the in-service and pre-service teachers establishing their careers within a complex cerebral and technological education environment (McAuliffe, 2016; Schleicher, 2018; Tait & Faulkner, 2016). Neoliberalist currency frames teachers as flexible technicians, offering an alternative understanding of "what it means to have and exercise agency" (Golden, 2018, p. 2), and cannot be restricted to the notion of divergent thinking being the single representative of innovative education models. There remains a place for convergent processes in validating STEAM content to avoid a 'ticking boxes' approach to prescribed cross-curricular outcomes (Herr et al., 2019; McAuliffe, 2016). It has previously been acknowledged that for teachers to see themselves as contributing collaboratively to system leadership is as important as the mutual value attributed to students seeing their teachers learning (Schleicher, 2018). Schleicher (2018) places the sense of ownership in terms of teacher praxis relative to student experience, at the heart of productive learning and professional autonomy. Thereby creating a culture of innovative learning that addresses education futuring through valuing non-routine cognitive skills, such as imagination and creativity, as well as social and emotional skills (OECD, 2019)

1.1.2 *STEAM's transdisciplinary divergence* and *convergence*

Studies of multiple creativities in education show that STEAM learning enhances multi-perspectives, underpinned by the natural logic of convergence available to all humans (Burnard & Colluci-Gray, 2020; Herr, Akbar, Brummet, Flores, Gordon, Gray & Murday, 2019; McAuliffe, 2016). Such constructivist processes allow us to consider divergence as also disruptive, positioning STEAM in the role of guide. What is meant here is that STEAM guides new learners into territories where the language and environment of logical and creative thinking are appropriately merged, reconciling ambiguities, tensions and dilemmas outlined in forecasts such as the OECD's Learning Compass 2030 (OECD, 2019).

The body of literature considering "what if" as a creative educational tool in transdisciplinarity, argues that "what if?" requires engagement with creativity, imagination and curiosity, concurrent with potential contribution to entrepreneurial thinking (Fleming, Gibson, Anderson, Martin, & Sudmalis, 2016; Craft, 2015; Wagner, 2012). In much of their research emphasising exploration and discovery, Fleming *et al.* (2016) also deem imagination to be a possible disruptive or subversive contribution to the education environment, presenting a “certain irony that qualities associated with the imagination such as pondering **‘**what if**’** can be thought to fit comfortably within frameworks attached to knowable Key Performance Indicators” (p. 436) . Scholars have long agreed on the impact of creativity and imagination in education being transformative for teachers and students (Craft, 2015; Eisner, 1985; Greene, 2018; Robinson, 2010). For this reason, STEAM education must necessarily engage with curiosity and imagination if it is to be considered innovative. Existing research also recognises the paradox acknowledging success in teaching as closely tied to student test results (*NMC/CoSN Horizon Report*, 2016: Golden, 2017; Schleicher, 2017). Therefore it is difficult for teachers to access rewards for developing and implementing innovative approaches to learning and teaching, which may be a deterrent to STEAM.

Studies over the past two decades have provided information on nations that enjoy high international testing outcomes coexisting with strong STEM agendas that concentrate on 21st century skills. Such skills include inquiry processes, problem-solving, critical thinking, creativity, and innovation, as well as a strong focus on disciplinary knowledge (English, 2016; Freeman, Marginson, & Tytler, 2015; P21, 2002). Aligned with such research, both zeitgeist acronyms STEM and STEAM reveal the importance of nurturing balanced transdisciplinary connections to encourage profound conceptual contemporary understandings. The risk for educators is to promote and encourage the idea that participants in STEAM learning might begin to identify themselves as trans-disciplinarians in a world led by both convergent *and* divergent experiences. Australian Curricula prescribe such experiences and understandings, promoting the need for unified cultivation of human capabilities defined through four 21st century Cs: communication, collaboration, creativity and critical thinking. Emotions and thought are also key players in the mix (Rahm, 2016), encouraging the inclusion of forthcoming 22nd century attributes described in the literature more recently, as connection, care, community and culture (Santone, 2019; Tomlin, 2018). Both C sets fit appropriately with the OECD Learning Compass 2030, that promotes a cycle of action, reflection and anticipation within the culture of future learning (OECD, 2019).

Much research related to growing 21st century skills promotes a transformed pedagogical environment organised around interrelated motivational elements including play, curiosity, fearlessness, passion, and purpose (Craft, 2015; Golden, 2018; Wagner, 2012). Teachers may perceive a lack of knowledge or confidence in their own skills to coordinate such elements in their pedagogical practice. Therefore, for teachers, STEAM may be a valuable conduit for *permission* to play, be curious, passionate and fearless, indicating how challenging oneself beyond regular comfort zones can result in transformed teacher self-perception. This provides compelling reasons for encouraging transdisciplinary STEAM education in a range of learning contexts. In my research for this thesis, the learning context under scrutiny is STEAM teacher professional learning (PL).

1.1.3 The transformational potential of STEAM

The 'tools of thinking', making up the complex STEAM mixture proposed by Root-Bernstein and others working in transdisciplinary fields, have been operational in the process of discovery for a long time. However, such studies reveal that

> "most scientific teaching occurs only in these secondary languages of words and equations, with little or no mention, and often less training, in the use of non-verbal, non-mathematical modes of thought or the importance of perceptual thinking tools, intuition and emotion" (Root-Bernstein, 2019, p. 12).

The key to successfully connecting disciplines is to make deliberate effort to relate ideas and make the intersections between them explicit (Fogarty, 1991). STEM teachers who are willing to realise those intersections in their practice by teaming up with colleagues in the arts are regarded by Taylor (2016) as visionary educators. McAuliffe (2016) considers the same teachers as highly prized and sought after in education systems, encouraging collaborations between the STEAM disciplines as a new paradigm for primary, secondary, undergraduate and postgraduate education.

In her work related to growth mindsets, Dweck (2008) argues that abilities can be cultivated. It is important to consider the cultivation of a STEAM education environment, in which teacher mindsets are encouraged to grow, to be an exemplary model of collective learning that incorporates the best features of teacher, students and subject matter. This is why 'thinking' and 'making' is so important in STEAM. STEAM is a learning environment where all participants in the activity acknowledge that "the hand has its own intentionality, knowledge and skills" (Pallasmaa, 2009, p. 21). The current global renaissance of tinkering and making, of which teachers may or may not be aware, nevertheless demonstrates the readiness of educational environments to embrace the intelligence, thinking and skills of the hand, and it would be a great shame to foreground 3Rs pedagogy that is blind to the relationship between the mind and making. Pallasmaa (2009) suggests the sensory realm exists as enabler for a full understanding of our capabilities as physical and mental beings, while Csikszentmihalyi and Robinson (1990) consider non-rational elements of consciousness as equal contributors to the construction of knowledge in wholistic learning (Csikszentmihalyi & Robinson, 1990). STEAM's potential for holistic understanding is manifested in the blending of the aesthetic experience with the action of problem solving, with a view to creating an aesthetic product. While problem solving through STEAM was not the focus of my research, the type of STEAM learning implemented throughout the study inherently incorporated problem solving due to the manual, technological, systematic and theoretical components included in each activity undertaken by the teachers in STEAM PL.

Physically modelling the intersections between the arts and STEM can have a powerful effect on learning. Yet it is the physicality of making that often scares teachers operating outside the arts and design, as they are generally settled in their capacity to operate within the comfort of knowledge expertise and regular practice (Eisner, 2002; Nutchy, 2012; Tait & Faulkner, 2016). My research points to the acute discrepancy of maintaining the belief that transdisciplinarity relies on the knowledge and skill of individual teachers working singularly at the peak of their expertise. While Taylor (2016) surmises a modest scale of STEAM learning can be achieved by an individual innovative teacher, collaborating in STEAM affords teachers the permission to be un-expert, relying more fittingly on cooperation for transdisciplinary success. Introducing disparate ideas and trying to connect them within a STEAM learning activity requires strenuous planning and motivation from the content contributors, for a successful experience to be attained. The literature reminds us that it cannot be assumed that teachers or students will understand the connections automatically (Daly, Mosyjowski, & Seifert, 2016; Eisner, 2002; Fogarty, 1991). The construction of STEAM learning programs undertaken in my research required extensive planning in collaboration with the participating teachers. Consequently, the teacher emotionality ran high as personal and professional comfort zones were pushed, sometimes to very precarious limits.

Emotions expressed through teachers' words and body language during participation in STEAM learning might substantiate how teachers' STEAM connections have been successfully enlivened. Frequently, this is how the impact of STEAM learning on the teachers' self-concept can be measured. My study tracks how learning STEM concepts can be melded with creative visual experimentation so that the experiences are rendered memorable, enabling the teachers to discover new aspects of self during the process of creating and making. Maeda says there is no greater integrity "no greater goal achieved, than an idea articulately expressed through something made with your hands" (Maeda, 2012, p. 4), yet many teachers find their thinking hands lying still. My study seeks to contribute to the field of education research that demonstrates how enlivening the often dormant hands of subject specialist teachers, is potentially transformative. My study also aims to show how teachers' release of anxiety associated with activating a relationship between STEM and the arts, can be liberating in the sense of enacting play, curiosity, passion, fearlessness and purpose.

1.2 Research Aim

The *Value of ME in STEAM* examines the emerging role of 21st *and* 22nd century Cs in the context of co-creation and delivery of challenging STEAM learning in secondary school settings. Some uncertainty exists about the relationship between teachers' emotions and learning in transdisciplinary STEAM contexts. My research aims to assess the effect of STEAM learning on the personal and professional identity of a specific group of participating teachers, with a view to understanding how teachers' emotional responses to transdisciplinary learning add value to the existing body of research related to STEAM PL.

1.2.1 Research Questions

There are two primary aims of this research: 1. Using STEAM to reinvigorate teachers' thinking about effecting pedagogy across disciplines, and 2. To gauge how emotions contribute to such development. Hence, the research questions underpinning the study are:

1. How can STEAM activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?

This question is related to the creation of a model of professional learning where teachers gain a sense of self-understanding through engagement with specific STEM concepts approached through an arts perspective. It aims to provide circumstances within which exposure to the intersections of those things are relatable and meaningful in the lives of the teachers.

2. How do emotions experienced during engagement in STEAM activities enhance or detract from the teachers' professional and personal identity development?

In the context of this research, the teachers' professional and personal identify development can be described as nuanced shifts in awareness, experienced through learning in STEAM. Emotions might include outlaw emotions such as fear, irritation and resistance, as well as activity emotions experienced through productive persistence. These emotions present as excitement, joy, elation, and achievement, both defined in key terms later in this chapter.

1.3 Conceptual Framework

Devising a conceptual framework within which socio constructivist ideas merged with phenomenography was a valuable interpretivist approach to this research. I refer to this dual theoretical framework as 'hybridised constructivism', taking the Vygotskyan features of social interaction shaping the learning process, and placing it in a specific time and place, enacted with specific people, and shared with significant others. Applying a neuroscientific view of hybridised constructivism draws on notions of bending, breaking and blending (Eagleman, 2018). *Bending* the STEAM interpretations through a human emotional lens, *breaking* through a temporal phenomenological approach, to include phenomenographic notions of mapping human experiences, by *blending* social constructivist ideas surrounding 'learning by doing'. That is, with how one *feels* while learning by doing. The conceptual framework also draws on strengths of a paradigmatic constellation referred to by Lukenchuk (2013) as "four paradigms in slightly different configuration: prediction (positivist), understanding (interpretive), emancipatory (critical), and deconstruction (poststructuralist)" (p. xxvi). According to Lukenchuk, the concept of paradigm refers to an integrated set of etymological definitions resulting in a threefold meaning: "(1) a system of educational inquiry (2) a model, and (3) a way of knowing" (p. xxv). Each of these definitions have a resounding influence on the way STEAM education activities can be co-created, documented and analysed in current transdisciplinary focused learning ecologies. Thus, for my research to be useful in any way, it must be analysed directly or indirectly through the collective lenses of positivist, interpretive, critical and poststructuralist principles. Applying features of this paradigmatic constellation within a hybrid constructivist framework afforded my research with rich comparative analysis and greater potential for the study's contribution to knowledge (see Figure 1.1).

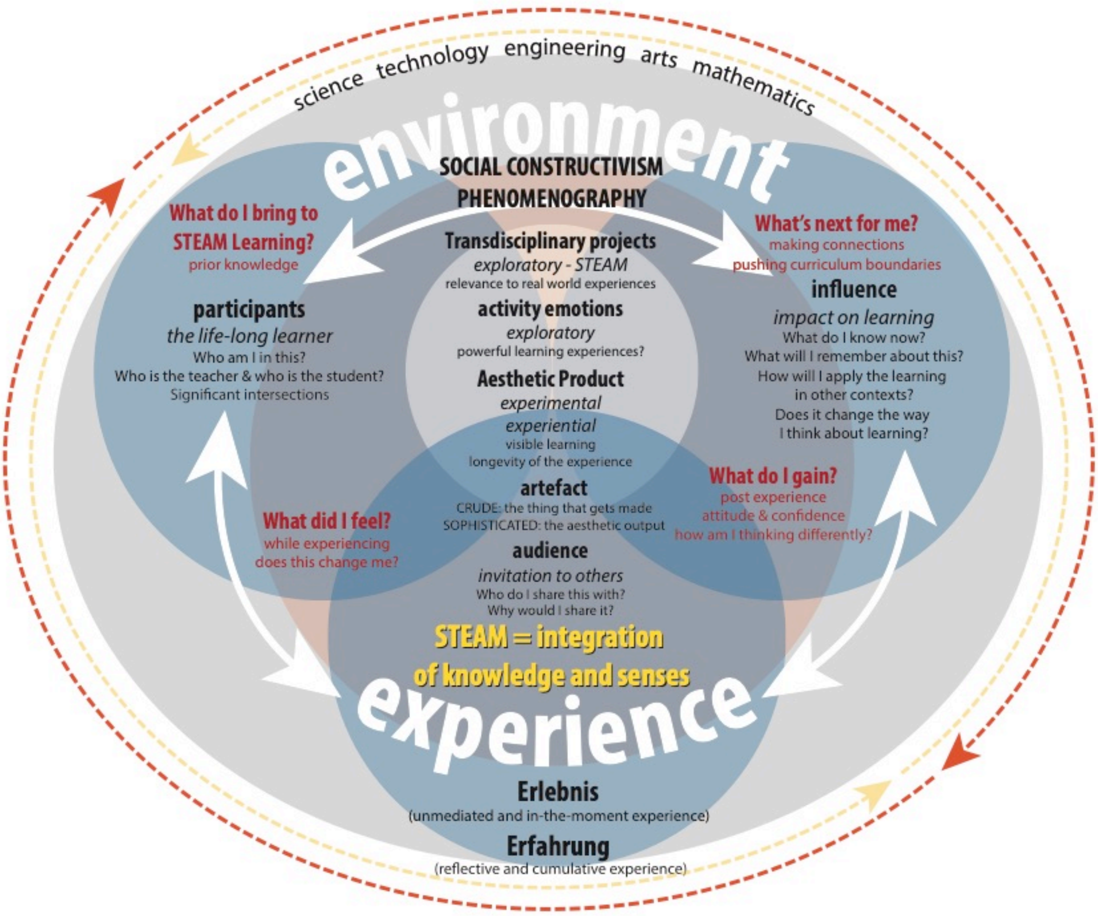


Figure 1.1 Conceptual Framework for the study.

In reference to Figure 1.1, constructivist interpretation of teacher practice provided acknowledgement of the value of prior experience and what this brings to a new situation. In the context of STEAM learning, there are many examples of content intersections in the wider world, waiting to be explored through curiosity and innovative pedagogy. Thus, it is the duty of the teacher/learner to bring real experiences of integrations and interactions, through their own accounts and descriptions, and embed these in new practice. Roth (1998) suggests, "there is no meaning *out there* and predating our experience, there are only acts situated within discursive and embodied access to a world that is always and already shot-through with meaning" (Roth, 1998, p. 9). By default, the primary goal of constructivist learning is to enable learners to "construct knowledge out of their exploratory actions on the environment" (Csíkszentmihályí, 1990, p. 149). In STEAM, the lifelong learner is able to enjoy experiential education via engagement, interpretation and application, resulting in cumulative connections between experience and learning. Ideas related to formative construction of knowledge through reflective and cumulative experience, referred to by Dewey (1938) as *Erfahrung*, cannot be separated from the influence of emotional activity within the in-the-moment experience, *Erlebnis*. The conceptual framework illustrated in Figure 1.2 shows how the research underlying my thesis continually returned to interpretation of teacher experiences using erlebnis and erfahrung as analytical tools.

1.4 Research Design

My research presents four case studies measuring the effect of STEAM learning on teachers' professional and personal identity. In the following chapters, the case studies are referred to as STEAM 1, 2, 3 and 4, ranked according to the size and scope of each. The case studies were conducted over two years from three schools' professional learning (PL) programs and one professional organisation. All participants in this research were considered *learners,* with acute focus on teachers as learners, including pre-service and serving teachers, members of schools' executive and myself as teacher/researcher. The total number of participants was 58, with intensive focus on 14 teachers. Accordingly, data collected through mixed methods supported my philosophical positioning as participant researcher, giving cause to the approaches I have taken to investigate the STEAM learning context. The complexity of the study required me to operate as participant researcher in the cases of STEAM 1 and STEAM 2. These, and STEAM cases 3 and 4 warranted varying degrees of teacher PL, delivered by the researcher (myself), or with additional support from executive STEAM team members. Self-immersion in teacher PL reinforced my aim to answer the qualitatively driven research questions outlined earlier in this chapter.

The Case Study methodology applied in this research resulted in appropriate provision of comparative analysis opportunities. Both qualitative and quantitative methods were used in this investigation. Data was collected across the cases through observation, experience sampling (ESM), formal and semi- formal interviews, group and individual reflections, and analytical memos (recorded ongoingly in field note entries). The feasibility of this research was reliant on appropriate size and scope of each case study. Consideration of appropriate selection of interviewee groups, their size and availability informed my approach. Data collection and analysis was supported by continual writing, evaluating the experience and outcomes of each formative activity undertaken as my study progressed. Since the STEAM programs were considered sustainable by two of the participating schools, aspects of my research evolved into a semi-longitudinal study. Hence, data was collected over two years in STEAM 1 and 3, and one year in STEAM 2 and 4. The benefits of a semi-longitudinal inclusion allowed for the pedagogy and practice in STEAM teaching to evolve, providing greater scope for comparative analysis.

All cases provided a structure and framework to observe, interview, document, reflect on and interpret data, through subjective and objective contextualised qualitative measures. As a consequence to the mixed methods data collection woven into the research design, features of narrative and appreciative inquiry traditions were incorporated into the overarching case study methodology. A principal element of narrative inquiry highlights the broadened scope of the relationship between the researcher and the researched. Drawing on narrative inquiry permitted me to present a relational understanding between myself as researcher and the actions and interests of the participating teachers – their journey, their stories. Similarly, the generative nature of appreciative inquiry, afforded investigation of the participating teachers' capacity for rejuvenation and innovation, encouraging transformed self-perception during and on completion of the STEAM learning undertaken in PL. In terms of experiencing activity emotions during STEAM learning and the effect of such on the teachers' sense of personal identity, more nuanced observation was recorded and supported using Experience Sampling (ESM) at key moments during the PL sessions.

Blending teachers' stories (narrative), with the joyful mystery in discovery (appreciative), brought flexibility, malleability, and adjustability of my research design to the comprehensive comparative analysis of the case study methodology. Appreciative inquiry, melded with the narrative, challenged the manner in which the data was analysed, in that boundaries between researcher and researched were often blurred, resulting in generative nuanced analyses of teacher transformation during the STEAM learning experiences.

1.5 Value of the study

STEAM programs of learning are authentic models of integration where content and experience merge. STEAM requires flexibility. It spans social and cross-cultural settings. It is adaptable, often collective, always collegial and never superfluous. It demonstrates intrinsic and extrinsic links between concepts, ideas and realities, and is often filled with wonder. STEAM is experiential. It represents the purpose of integration. 21st century identities are bound in STEAM, as those of centuries past; consider Aspasia, Aristotle, Leonardo, Einstein, Buckminster-Fuller.

The point of difference between this study and others related to integrated learning is that the research is primarily focused on the way STEAM experiences influence the identity development of the teachers involved. There is nothing new about theoretical STEAM content. Schools have been teaching science, maths and engineering for centuries. Schools have also been teaching with technology as it evolves in all its forms, from the use of chalk and boards to record information, and hammers, chisels, needles and thread to make things, right through to current and emerging digital image manipulation and fabrication. The same can be said for the arts, including languages and humanities. For all that, STEAM is inclusive, representing connections between the sciences *and* humanities, language arts, dance and physical movement, drama, music, visual arts, design and new media. The STEAM content co-created and utilised in teacher PL in this study relied on the fact that there was no other way to produce the desired visual aesthetic outcome unless the teacher participants engaged with STEM from the beginning. It would seem that the current prevalence of STEM and emergence of STEAM, as zeitgeist acronyms in the education arena, implies that transdisciplinary understandings are, in fact, infiltrating the so-called siloed fields of knowledge operating in many secondary schools today. Despite this, the experience of teaching sideways to one's expertise is troublesome for many educators. Even scary. Hence the value of my study lies in the teachers' fear-to-fearless journey, wherein the creation of a STEAM learning environment resulted in openness to challenge that nurtures growth mindsets.

Permission to play, for teachers, demands courage. My study demonstrates the importance of promoting and explaining how fears related to a STEAM learning trajectory were overcome, in order to create a unique, playful and positive learning experience for students and teachers alike. STEAM is where teachers co-create spaces filled with possibility, to directly experience learning together with peers and students. Robinson (2001) extolled the virtue of creative imagination when asking for a paradigm shift in the way we educate, drawing on examples of children's extraordinary capabilities for innovation (Robinson, 2001). It is important to acknowledge the connection between those extraordinary capabilities and opportunities for teachers to be inspired by what the children naturally do: play, be curious, fearless, passionate, operating with sense of purpose. These attributes prescribe the outcome of transdisciplinary learning, within which teachers working in cross-curricular settings often observe critical discovery moments where interconnected learning systems are explored and curriculum boundaries broken, if for a short time only.

1.6 Defining key terms

STEM

STEM is generally understood to be the combined knowledge areas of science, technology, engineering, and mathematics. A range of definitions of STEM education has emerged to include broad and individualised perspectives taking multidisciplinary approaches to developing learning programs. Different interpretations of STEM education have become problematic issues for researchers and curriculum developers. In acknowledging the lack of an agreed-upon definition, the California Department of Education (2014) provides a broad perspective on STEM education, namely, **"**[STEM]**…** is used to identify individual subjects, a stand-alone course, a sequence of courses, activities involving any of the four areas, a STEM-related course, or an interconnected or integrated program of study**"** (in English, 2016, p. 2). The Australian Government's *National STEM School Education Strategy, 2016 – 2026* considers STEM literacy is increasingly becoming part of the core capabilities that Australian employers need. Thus, the journey into STEM promotion begins when we open our children's eyes to the possibilities of science, technology, engineering and mathematics. Often, the gateway to this path can be found in the Arts.

STEAM

The influence of the Arts in STEM learning, while currently slowly emerging, is historically omnipresent. Drawing on accounts of what the arts offer the sciences, research in the area of STEAM education since the 1950s acknowledges the combination of science and the arts as "essential for producing a creative, scientifically literate, and ethically astute citizenry and workforce" (Taylor, 2016, p. 92). In Australia, the national curriculum defines the Arts as the range of key learning areas including drama, dance, music, visual arts and media. McAuliffe (2016) defines the Arts as "Physical, Fine, Motor, Language and Liberal (including; Design, Architecture, Sociology, Education, Politics, Philosophy, Theology, Psychology and History)" (p. 2). Being able to recognise and visualise critical intersections between practical subject content and theoretical concepts leading to creative realisations in an Arts context is now not only explicitly linked to manual and digital making, but to modelling and visualising in the sciences. For teachers to foster such skills in their students necessitates the ongoing cultivation of similar skills in the teachers' own thinking and learning.

Transdisciplinarity

Described as part of an expanded discipline continuum, transdisciplinarity provides a model of learning within which links among isolated issues are explored, interrelations discovered, and inclusive solutions are proposed (Cranny-Francis, 2017). The flow of knowledge connections between learners, concepts, and the world, with a view to applications to real-world problems, lies at the heart of transdisciplinary learning. The literature views the complexity of authentic transdisciplinarity as more than just knowledge and skill crossing, but rather, the multifarious shape of the learning experience itself (Bernstein, 2015; English, 2016).

Activity emotions

These are the human emotions which influence transformation. In the context of STEAM learning, activity emotions are the felt experiences that might contribute to the growth mindset identified by Dweck (2008), or emotions experienced in moments of flow (Csikszentmihalyi, 1996), or during an aesthetic experience (Robinson, 2001). In this study, activity emotions emerge as dialectical influences on teachers' personal learning trajectory. The general affective states including moods and emotions, in conjunction with instructional strategies for investigating challenges in relation to collaborative involvement, predicates the climate within which the STEAM projects enacted in my research were explored and documented. The literature shows that academic emotions are quite nuanced, influenced not by motivational aspects alone, but by much more contextual information such as "the types of interactions, their content, duration, intensity, and levels of challenge" (Meyer & Turner, 2002, p. 382).

Outlaw emotions

Aligned with activity emotions, Jaggar's (1989) definition of outlaw emotions includes feelings of fear, anxiety, trepidation and resistance. My research views outlaw emotions as powerful contributors to the teachers' STEAM learning experience. Such might be described as experiences where the combination of knowledge, emotions, environment and audience reaction provide peak sensory responses to new ways of thinking, knowing and being.

1.7 Overview of thesis structure

The following chapters demonstrate how the STEAM case study milieus were pedagogically challenging for participant teachers. My investigations recorded subtle and nuanced emotions expressed in the teachers' liminal states during STEAM PL, for the purpose of measuring professional or personal transformation. Chapter Two begins by laying out the theoretical dimensions of the research, looking at three areas of current empirical literature. The intention of Chapter Two is to conceptualise and contextualise creative processes and relevant research associated with aspects of STEAM education in relation to transformative teacher PL. Theory and practice related to transdisciplinarity forms the first part of the literature reviewed, in alignment with the aims of my research. The second aspect of literature reviewed is concerned with the concept of activity emotions in terms of human affect during STEAM PL. The third arm of the literature review explores connected pedagogical and curricular threads, interweaving STEAM with the creation of an aesthetic product, an aesthetic experience and an aesthetic sensibility for the participating teachers. Overall, Chapter Two presents the body of literature demonstrating how teacher attributes of curiosity, passion and purpose collide with elements of fearlessness and willingness to play. These are the innovation attributes Wagner (2012), Craft (2015), and Tait and Faulkner (2016) consider necessary for teachers to become edupreneurially agentic.

Chapter Three is concerned with the methodology used for this study. The third chapter presents the research design, including the data collection timeline. This chapter explains the methodology used, arguing that the case study, combined with features of narrative and appreciative inquiry was the most suitable approach to provide answers to the research questions. The fourth chapter analyses the results of qualitative data collected throughout the cases, using mixed methods of observation, interviews, group reflections, and analytical memos, with support from quantitative elements collected through pre and post surveys and ESM. Through the data analysis, Chapter Four presents the ways that emotional, aesthetic and experiential elements of STEAM PL, granted many teacher participants the opportunity to experience a different view of themselves.

Drawing on data analysis presented in Chapter Four, the next chapter discusses the epistemological strength of my research findings in light of existing studies in STEAM teacher learning. The findings discussed in Chapter Five are broadly supported by discoveries related to STEAM's transformative capacity for teachers, plus the importance of collegial support structures in STEAM education, and the value of recording teachers' emotions during STEAM PL. Acknowledging a range of teacher traits one might expect to encounter when designing STEAM PL with pedagogical challenge in mind, provides a vital contribution to the discussion presented in Chapter Five. These are the types of teachers who are unfamiliar with transdisciplinary learning, yet my study shows how each added value to the STEAM experience, due to willingness to risk traversing perceived knowledge boundaries, even if the crossing might fail. On the question of effecting teacher transformation, this chapter demonstrates the influence of dialectical emotions experienced during STEAM learning. Such emotions encouraged shifts in teachers' self-perception and identity as STEAM challenges were accepted, enacted and overcome. Most importantly, Chapter Five's discussion aims to show how transdisciplinary STEAM PL contributes to the concept of 21st and 22nd century futuring that values an education system within which care, connection, culture and community are of equal standing to communication, collaboration, creativity and critical thinking.

The thesis conclusion in Chapter Six presents the axiological positioning of my research in relation to ongoing studies in the area of STEAM education. The final chapter indicates teachers' productive persistence as the most energetic and transformative element in the collaborations. Such actions confirm Hattie's (2012) view of teachers' demonstration of apparent care and commitment to peers, reminds us that we are all learners and we are all human. More specifically, Chapter Six outlines how my research contributes to a deeper understanding of the effects of transdisciplinary practice on non-generalist teachers, including personal and professional affect realised through teacher emotions experienced during STEAM PL.

Together, the following chapters aim to weave a complex web of interpretation based on the dual framework of phenomenography and social constructivism, focusing on two research questions: (1) How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?; and (2) How does experiencing activity emotions in STEAM projects enhance or detract from the teachers' personal identity development?

What my thesis indicates is how a treasury of unique STEAM ideas put into practice can be personally and professionally transformative for teachers, even if only for the duration of the STEAM practice. Considering STEM explorations through an Arts perspective, the existential truth is that the connections have always been there. STEAM is not new. It is the responsibility of STEAM educators to encourage self and student awareness of such connections if we are to grow 21st and 22nd century skills across the education field. To develop a full picture of the value of STEAM for non-generalist teachers, additional studies will be needed to ascertain how authentic transdisciplinary STEAM encourages teachers to view their own knowledge through different lenses, potentially viewing themselves in alternative ways. Still, encouraging teachers to dive into the deep end of STEAM not-knowing, and collecting their stories as they plunge, provided the rich narrative intrinsic to this study. Analysis of the teachers' stories makes it possible to conclude that for teachers, the 'quiet thrill' of achievement, as Goleman (2006) puts it, can indeed, be identity shifting.

Chapter Two – Literature Review

"I am who I am not yet" (Greene, in Pinar, 1998, p. 1).

Three areas of current empirical literature have been reviewed for this study. Each attempt to conceptualise and contextualise creative processes and current research related to aspects of STEM and STEAM education, consequently forming a framework for the research design. Theory and practice related to transdisciplinarity forms the first part of the literature review. Motivation for transdisciplinary education is presently renascent, emerging from 'integrated' and 'cross curricular' models, with a view to connecting mainstream learning with actual and relevant real-world settings. STEAM, by nature of the acronym, *is* transdisciplinary. STEAM learning therefore presents a perfect environment to expose connections between content areas, still frequently taught in traditional settings with minimum conceptual intersection.

The second aspect of the literature review is concerned with the concept of activity emotions. Studies of emotions and how they influence learning, even those considered 'outlaw' (Jaggar, 1989), or "outside emotional hegemony" (p. 160) have been identified as impactful in STEAM contexts. Research describing the potential of STEAM education has indicated its powerful learning experiences, where the combination of knowledge, emotions, environment and audience reaction collide, provide avenues for fundamental observation of peak sensory responses to new ways of thinking, knowing and being. Interconnected themes drawn from Wagner's (2012) *Creating Innovators - The Making of Young People Who Will Change the World*, underpin this study. Themes including play, curiosity, passion, fearlessness and purpose. While STEAM education research has been primarily focused on students and young learners, there is some literature presenting their teachers are crucial concurrent targets for study. Focusing on teachers as learners in this review has afforded the emergence of ideas associated with the formation of adult identity and professional agency, creativity, emotions and personal experience.

The third arm of the literature review explores connected pedagogical and curricular threads, interweaving STEAM with the creation of an aesthetic product, an aesthetic experience and an aesthetic sensibility overall. The interplay between STEAM theory and practice forces teachers to engage with learning in disciplines other than those in which they are considered experts. Such interplay may alter a teacher's life view. Studies finding interrelationships and connections between fields of influence, have often disrupted and informed life systems (Keane & Keane, 2016). In terms of STEAM education, Keane (2019) has also described life systems through a lens of Wilson's (1999) Consilience Theory of how *everything connects,* yet the synthesis of learning through such cause and effect connections finds teachers continuously situated themselves "on the breach" (Keane & Keane, 2016, p. p.62). Hence, it is imperative for common threads between STEAM learning experiences to be exposed if teachers are to embrace the personal and professional potentiality of the shifting knowledge fields inherent in transdisciplinarity.

2.1 Transdisciplinarity

Transdisciplinarity emerged in response to concerns about the dangers of compartmentalising areas of knowledge into siloes. Bernstein (2015) places Swiss psychologist Jean Piaget at the origin of *transdisciplinarity*. The word itself appears in a 1970 seminar on interdisciplinarities in universities sponsored by the Organisation of Economic and Development (OECD) and the French Ministry of Education, held at the University of Nice. The OECD seminar investigated possibilities of new syntheses of knowledge and the notion of interconnectedness and was led by exposing theories of systems addressing human centred preferred futures (Bernstein, 2015). Not unlike the situation we find humanity facing today. Transdisciplinarity encouraged ethical and balanced collaboration between those proffering expertise in different knowledge areas, and collective intent to tackle real problems.

Discourse related to integrated education is not new. Integrated learning and teaching exist as a pedagogical model founded on collaboration and strategic planning for connected curricula. The United Nations Educational, Scientific and Cultural Organisation (UNESCO) identified shifting definable fields of knowledge since the monitoring of global education was implemented early in the 21st century (UNESCO, 2017). The previous chapter presented a snapshot of how such shifts have been a result of increasing specialisation and accountability related to overlapping domains. Current evaluations related to achieving quality education categorise accountability as both individual and collective responsibility, action oriented or moral (Hattie, 2016;

Schleicher, 2018). The existing literature on re-determining the need for collaboration, communication and critical thinking across disciplines and fields of knowledge, has made sense of the reciprocal relationship between disciplines and experiences (Bernstein, 2015; Cranny-Francis, 2017; Finkel, 2016). Justifiably, the continued "tensions between STEM subjects and the arts and humanities in education" (Smith, 2018, Para. 17), prolong the position of STEAM learning as 'tricky'. Further to this, arts educators have found that

> STEM content articulates curriculum, assessment and examination regimes that are efficient and easily defined. Phenomena studied in the arts and humanities are subject to [myriad] different interpretations making it tricky to define knowledge and predict outcomes in the same way (Maras, in Smith, 2018, Para. 19).

Maras' (2018) comments refute the notion that Arts subjects lack rigour or complexity but certainly uncover the wicked problem of balanced integration into STEM.

More recent attention in Australia and local to New South Wales (the state in which this research is situated), states that priority must be given to advancing student numeracy and literacy skills across all levels of school education. Commissioned by the Commonwealth of Australia, *Through Growth to Achievement: Report of the Review to Achieve Educational Excellence in Australian Schools* (Gonski et al., 2018), urged us to get our children back to basics through revitalising the '3Rs' of 'reading, writing and arithmetic' in the classroom. For educators, there is now a greater need for STEM concepts to integrate with the arts (STEAM) across the wider curriculum for reasons that integration builds literacy not exclusive to language arts and applies numeracy that connects STEM to the real world (Henriksen & Mishra, 2020). The *NSW Government response to the NSW Curriculum Review – final report* (2020), recommends the content and structure of a proposed new curriculum include the view that "most syllabuses are 'overcrowded' with content and need to be stripped down to focus on what is essential in each subject" (p.6). Responding to this recommendation, the report states that new syllabuses will focus on core learning in each subject area, "identifying essential concepts, knowledge, skills and understandings" (p.6). Further to this, the NSW Government is committed to reducing "by approximately 20 percent the number of school-developed elective courses in secondary school" (p.12). While such authoritative emphasis on segregated subject specific thinking is not useful for transdisciplinary

STEAM learning, the report does maintain the need for integrated subject knowledge and the practical application of that knowledge, particularly at the secondary level. Imperatives for the Australian innovation, science and research system, include 'culture and ambition' (see Figure 2.1).

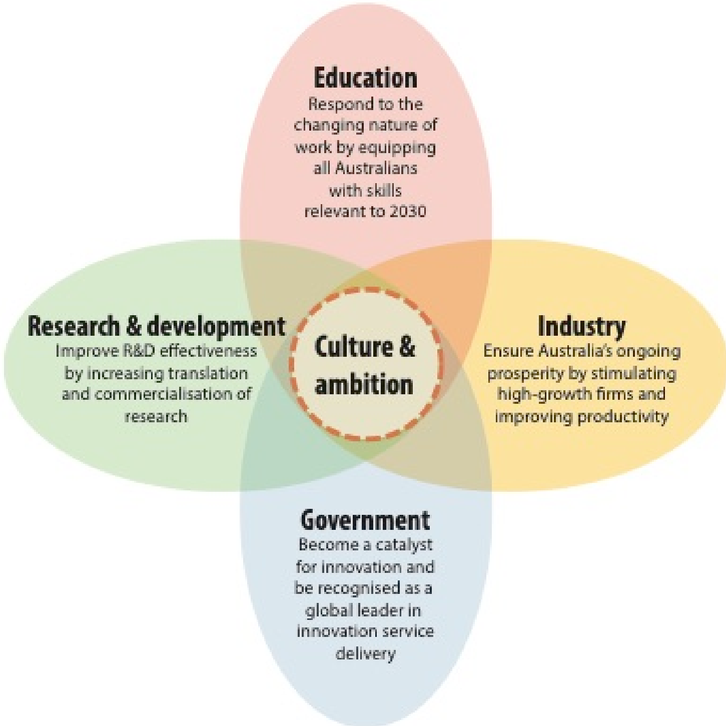


Figure 2.1 Five imperatives for the Australian innovation, science and research system (Ferris, 2017, p. 3)

The education quadrant feeding into 'culture and ambition' speaks of equipping Australians with skills relevant to 2030, as does the Learning Compass 2030, released by the OECD in 2019. Comparatively, the attributes necessary for creating and maintaining a culture of innovation, according to the OECD concept, rely as much on social and emotional skills as cognitive and technological skills (OECD, 2019). Reports of this type consistently emphasise the challenge for educators is to embed the understanding that "Schools are critical: not simply because they nurture our abilities but because they shape our attitudes", a view put forward by Professor Ian Chubb, former Australian Chief Scientist (Chubb, 2015, p. 7). OECD (2019) studies consider "metacognition, lifelong learning and understanding other cultures" as adaptive education futuring tools. It would seem the same arrangement is also necessary for teachers to reach their full potential. This is why 'thinking' and 'making' is so important in STEAM.

What is missing from the Australian reports is the notion of how STEM industries might benefit from integration with non-STEM work and practices. In his introduction to the STEM Workforce report, Dr. Alan Finkel (Australia's Chief Scientist at the time of writing) refers to non-traditional ways of educating and researching in STEM areas. Finkel suggests "no clever country would encourage its most STEM-literate people to pursue only traditional research paths" (Finkel, 2016, p.iv). Not surprisingly, along with creativity, physical and practical skills associated with the arts have been lauded by the OECD (2019) as crucial to the development of empathetic intelligence, and enhancement of emotional engagement, commitment and persistence. Finkel goes on to say that his own experience would reveal that he found opportunities in unexpected places (Finkel, 2016). In this way, traditional modes of education may be disrupted by fully integrating content in ways that are imaginative and challenging while still relatable to real-world concepts.

Referring to the five imperatives for creating an innovation culture in Australia innovation, science and research system (see Figure 2.1), it is possible to think of STEAM connections as vital to blending discipline rigour with the way content relates to interest or engagement. STEAM learning attempts to subvert familiar teaching approaches and asks the learners (teachers and students) to divert thinking away from rigid specificity, without losing sight of the content relevance to real world situations. In the literature related to the confluence of divergent and convergent thinking, the relative importance of STEAM learning approaches has been subject to considerable discussion (Burnard & Colucci-Gray, 2020; McAuliffe, 2016; Root-Bernstein, 2019). Understanding discipline differentiation has led to better knowledge of how reciprocal relations, performance and altruism in education can be achieved in small, close-knit groups as well as distinct pedagogical collegial relationships (UNESCO, 2017). Bernstein (2015) proposes "transdisciplinarity is perhaps above all a new way of thinking about, and engaging in, inquiry" in a "world that has become 'too big to know" (p. 1). Such studies have suggested the word itself has become an important presence in the landscape of integrated education, recognised by some researchers as a *wicked problem*.

The 'wicked problem' of integration has spread across a multitude of domains with some researchers defining education for the 21st century as an example of a 'wicked' problem itself (Bernstein, 2015; Cranny-Francis, 2017). The term was originally identified by design theorists Horst W. J. Rittel and Melvin M. Webber (1973), and more recently popularised through human centred designer Bruce Mau, within his exploration of complexity: *Incomplete Manifesto for Growth* (Mau, 1998). Focussing on similar complexities found through integrating Arts and STEM knowledge areas has raised significant interest in transdisciplinarity. Such interest has risen from a need to lessen the anachronistic view that STEM learning lacks creativity and Arts learning lacks scientific rigour (Burnard et al., 2018; Smith, 2018). A number of media reports published over the past five years (see section 1.1) have exposed and enflamed the wicked problem of balanced transdisciplinarity in STEAM. Such problems have been addressed in studies that reveal synergistic learning outcomes to be naturally fluid integrations, as the theory of a close relationship between Arts and STEM is considered innovative and forward thinking (Keane & Cimino, 2019; McAuliffe, 2016; Sousa & Pilecki, 2013). Correspondingly, STEAM synthesis through the lens of Consilience may provide new learning environments in which teachers are able to "put together the right information at the right time, think critically about it, and make important choices wisely" (Wilson, 1999, p. 294). Cranny-Francis' (2017) interpretation of cooperative discipline inputs also calls for balance in unity, where the loudest voice should be that of the softest speaker. Thus, it appears that balanced representation between disciplines and their spokespeople calls for interrelated hybrid thinking.

According to the NSW Government response to the NSW Curriculum Review (2020), the already 'overcrowded' syllabuses requiring stripping down, maintain the hold that some educators, policy writers and curriculum developers exert in relation to subject specific knowledge construction. To reiterate, the NSW Government response upholds the notion of discreet subjects being a most effective method of focussing on learning core content. While this supports the importance of segregating key learning areas, the response simultaneously contradicts its own focus on the need for correlating essential understanding, in the sense that such overlapping leads to cultural growth and innovation (Ferris, 2017). The report itself, maintains the need for integrated subject knowledge, and as such, warrants a greater understanding of forms of integration at the curriculum design level. In this study I consider integration, or transdisciplinarity, as hybridised constructivism, responding to the need for de-compartmentalising of knowledge in a STEAM context.

Hybridised constructivism, that is, *doing*, *being* and *becoming*, via STEAM education experiences, is a way of providing an opportunity to explore interconnectedness in learning activities (Hanney, 2018). McAuliffe pragmatically states "the implementation of two traditionally opposing disciplines means it becomes the task of the educator to develop and/or implement the curriculum" (p. 4). Braund & Reiss (2019) consider hybridised constructivism alludes to the reinvigoration of STEAM where the idea is "to work in a transdisciplinary way, avoiding artificial combinations (or separations) of subject disciplines" (p. 10). Teachers or facilitators help students make connections by providing the opportunity for those connections to be apparent and realised. English (2016), in *STEM education K-12: perspectives on integration*, expounded areas of research related to lifting the profile of STEM in integrated curriculum, while simultaneously emphasising the need for balanced STEM student outcomes. Recommendations from English (2016), suggest that the multifarious concept of spanning discipline boundaries warrants basic understanding of the definition of integration as **"**working in the context of complex phenomena or situations [using] knowledge and skills from multiple disciplines**"** (English, 2016, p. 3)**.** English (2016) proposes a more comprehensive perspective on integration where different forms of boundary crossing are displayed along a continuum of increasing levels. Table 2.1 shows how progression along the continuum involves greater interconnection and interdependence among the disciplines (Vasquez, Schneider, & Comer, 2013, in English, 2016).

Table 2.1: Increasing levels of integration (adapted from Vasquez et al, 2013 in English, 2016).

Form of integration	**Features**
Disciplinary	Concepts and skills are learned separately in each discipline
Multidisciplinary	Concepts and skills are learned separately in each discipline but within a common theme
Interdisciplinary	Closely linked concepts and skills are learned from two or more disciplines with the aim of deepening knowledge and skills
Transdisciplinary	Knowledge and skills learned from two or more disciplines are applied to real-world problems and projects thus helping to shape the learning experience

Citing Piaget (1972), Bernstein considers the status of transdisciplinarity as a higher stage of interdisciplinary relationships places integration "within a total system without any firm boundaries between disciplines" (Bernstein, 2015, p. 138). Similar to Vasquez et al., Table 2.2 describes Cranny-Francis' expansion of the discipline continuum, outlining the effect of progressive discipline integration within a human interrelation context.

Table 2.2: Power relations between discipline integrations (adapted from Cranny-Francis, 2017)

Form of discipline integration	Features	Outcome	Effect
Cross/Multi	Juxtaposes separate disciplinary approaches without consensus	Lack of coherence or resolution	Uneven: chaotic, unsatisfying
Interdisciplinary	Different viewpoints from different disciplines assembled	Coherence missed	Loudest voice dominates
Transdisciplinary	Links among isolated issues explored and nature of issues re-thought and alternatives considered	Interrelations discovered and inclusive solutions proposed	All factors taken into account

Whilst motivation to contribute to multidisciplinary learning is admirable, much of the academic attitude towards multidisciplinarity, according to Cranny-Francis, lacks coherence in terms of collaboration and balanced content knowledge, frequently resulting in unsatisfying experiences. True transdisciplinarity cannot rely on content alone but must take into account the human value of inclusiveness to achieve success (Cranny-Francis, 2017). Braund & Reiss (2019) cite Quinn's (2013) post-human education view of 'life-long' holistic teaching in regards to STEAM. That is, education which sees individuals playing "a part in knowing about themselves as a greater whole, rather than being seen as subservient participants in an epistemology valuing information and knowledge as superior to the individual" (p. 10). Transdisciplinary authenticity requires rejection of neoliberalist approaches to learning, where individualised modes of thought have obstructed the flow of knowledge connections between learners and also between the learner and their world (Prentki & Stinson, 2016).

2.1.1 Defining STEAM as transdisciplinary practice

Previous research has established that choosing between the Arts and Sciences is no longer a binary question but an exploration in creativities (Amabile, 1997; Bequette & Bequette, 2012; Herr et al., 2019). Locating the intersections between learning and teaching the Arts and STEM has reinvigorated a provocative and inspiring discussion between educators of all kinds. McAuliffe (2016) identified "those who are able to appreciate, integrate and function across the STEAM (Sciences, Technology, Engineering, Arts, and Mathematics) disciplines are highly prized and whose value is increasingly recognised" (p. 2). Amabile (1997) proposed creativity as "simply the production of novel, appropriate ideas in any realm of human activity, from science, to the arts, to education, to business, to everyday life" (Amabile, 1997, p. 40). Numerous studies have correlated the need for fresh innovative practice in education with that of business, noting that the rapidly evolving interdisciplinary nature of delivery in a technologically driven socio-cultural and political environment warrants our learning to prepare others and ourselves for a world in which we are likely to thrive (OECD, 2019; Schleicher, 2018; Tait & Faulkner, 2016). Amabile proposed such in 1997. The Education Council of Australia and Australia's Chief Scientist, Alan Finkel, recommended the same in 2015 and 2016 respectively (Finkel, 2016; *National STEM School Education Strategy, 2016 – 2026*, 2015). More recently, challenges identified by the Australian Council for Education Research (ACER) (Timms et al., 2018) contiguously claim that building STEM capacity is essential to the development and support of innovation and productivity, regardless of occupation or industry. Corresponding scholarly work by Peter Taylor, presented to ACER in 2016 cites Deloitte's (2015) report on the [information technology] IT worker of the future, arguing:

> that creativity is a key priority and that STEM educators need to embrace the arts in order to foster students' creative design and performance, using various media: IT leaders should add an 'A' for fine arts to the science, technology, engineering, and math charter – STEAM, not STEM (Taylor, 2016, p. 126)

Much of the literature on STEAM as transdisciplinary practice pays particular attention to the current global renaissance of tinkering and making, demonstrating the readiness of educational environments to embrace the intelligence, thinking and skills of the hand (Gulliksen, 2016; Pallasmaa, 2009; Patton & Knochel, 2017). Such studies have suggested the sensory realm exists as enabler for a full understanding of our capabilities as physical and mental beings, and is crucial to human investigation, interrogation and reinvention. What we know about transdisciplinary STEAM practice deals with Dweck's (2008) studies on growth mindsets, in that STEAM abilities can be cultivated. Similar views held by Csikszentmihalyi and Robinson (1990), Pallasmaa (2009), and (Hanney, 2018), have suggested transdisciplinary strategies applied to all learning may be greatly enhanced by both rational and non-rational elements of consciousness, generally experienced through permitting oneself to play and make, or stepping outside a perceived comfort zone surrounded by words and equations. It is important to note that the *maker* culture, or *makerspace* paradigm bequeaths learning as innovation, enterprising in that *making* becomes an elaboration stage of the creative process (Gardiner, 2016). Applying makerspace attributes to STEAM learning activities intends

> to create a STEAM-charged participatory culture that encourages people who were not previously inclined to code or solder to interact with science and technology in ways they had not before. (Barniskis, 2014, para. 2)

Maeda (2012) reframes creative activity as an "education in getting your hands dirty" (Para. 4), labelling such experiences as *critical thinking – critical making*. Maeda sees fearless problem-solving and critical thinking closely linked to *making,* and that making is a joyful experience. Dweck (2008) suggests that joy is contagious. In STEAM learning, emotional experiences rely heavily on transactional relationships, in which the subjective and personal experience, refers to a person's internal state, as in the experience of joy and happiness (Burnard, Jasilek, Biddulph, Rolls, Durning, & Fenyvesi, 2018; Craft, 2015). Such conditions are said to interrelate temporal, historical and environmental states with the objective of making the learning visible (Hanney, 2018). Previous research findings related to haptic sensations and embodiment (e.g. Maths in Motion (MiM) (Fenyvesi, Lehto, Brownell, Nasiakou, Lavicza, & Kosola, 2020)), have embraced the complexity of the STEAM experience, describing how the intelligence, thinking and skills of the hand, taken together with intellectual challenge, form a holistic learning situation.

2.1.2 Positioning STEAM as transdisciplinary innovation

Reviewing the literature connecting creativity and innovation with STEAM education has revealed how individual discipline methods are fundamental contributors to the collective construction of knowledge, simply by realising the power, nuance and complexity inherent in the pursuit of newness (Paavola, Lipponen, & Hakkarainen, 2004; Ritchhart, 2015; Roth, 1998). Newness, in this sense, is a metaphor for learning, one which strongly emphasises collective knowledge creation across disciplines. The complexity of such alignments in learning environments has necessitated curriculum co-creation in education, reflected in current Australian Curriculum cross-curricular priorities (ACARA, 2014b; Cranny-Francis, 2017; McAuliffe, 2016). Finkel (2015), in the introduction to (Australia's) *National STEM School Education Strategy* (2015), reported our best future is a future that builds on technology, innovation, ideas and imagination, but not technology alone. Of course, much of the literature has shown how digital technologies lend themselves to substantial explorative STEAM learning potential, suitably annexed by elements such as Craft's (2015) four Ps of the 21st century; "pluralities, playfulness, possibilities and participation" (p. 175). Therein lies an opportunity for co-creation of learning environments where students and teachers play to learn, alongside each other, bringing different skill sets to the learning ecosystem.

Creating cultures of innovation in teaching and learning require non-linear thinking. Wagner (2012) asks: "how to teach, recruit, and reward the flexible, creative, non-linear thinking that is required?" (p. 231). Support for the question relies on the view that it is no longer enough to increase teacher professional development without considering re-structure of curriculum design (Taylor, 2016). As Wagner (2012) indicates, we must present a *different* education and not simply supply *more* education, promoting the evolution of a more collaborative and reflective kind of leading educator, in an environment where forms of accountability are more face-to-face, reciprocal and relational.

> Authority still matters for successful innovation, but it is not the authority that comes with a position or title. It is the authority that comes with having some expertise, but it also comes from the ability to listen well and empathically, to ask good questions, to model good values, to help an individual more fully realise his or her talents – and to create a shared vision and collective accountability for its realisation. It is the authority that empowers teams to discover better solutions to new problems. (Wagner, 2012, p. 241)

Previous studies have shown that innovative teachers grow in confidence when they find and are supported by those who share the same unconventional perspective. They form a team (Hattie, 2012; Tait & Faulkner, 2016). Stinson (2013) found that the team has its roots in the notion of relational pedagogy, where understanding what it is to be human prescribes learning experiences as a natural evolution of our relationship with the business of living. Dweck (2008), Wagner (2012), and Tait and Faulkner (2016) have considered self-reflection crucial to enacting innovative collaborations, enabling innovative teachers to make wise decisions based on collective *and* individual discernment rather than external influence. Wagner (2012) reminds us to not "give in to the temptation that you can do this thing you want to do all by yourself. You can't" (p. 245). Studies on the power of integrative forces in learning (e.g. Barniskis (2014) and Ritchhart (2015)), point to modelling as an almost hidden dimension of teaching, where teaching is not just demonstrating, but a continuum of explicit to implicit sharing of "who we are as thinkers and learners" (Ritchhart, 2015, p. 125). Creating innovative learning and teaching cultures through transdisciplinary STEAM is dependent on such integrative forces, made powerful by acknowledging the valid input of varied content from individually skilled educators. Ritchhart (2015) and Wagner (2012) view this type of transdisciplinary modelling as non-linear creative inquiry and problem solving in which the embodiment of such learning characteristics leads to a motivated, innovative thinking culture.

Many educators consider STEM to be unequivocal inquiry-based learning. The transition to STEAM shifts and expands the context into inquiry-based *and* problem-based learning, underpinned by creative practical methods, and enacted by enthusiastic teachers. The existing literature related to developing such capacities in teachers (Collard & Looney, 2014; Ritchhart, 2015; Wagner, 2012), affords the contribution of new challenges to be viewed as permission for teachers to ask more questions beginning with *what if?* That is, questions, leading to the concept of *what do you do with what you know and what you don't know?* (Craft, Chappell, Rolf, & Jobbins, 2012; Wagner, 2012). Placed in the context of STEAM co-creation, there is little difference between the two in terms of how humans acquire knowledge and make sense of the world (Paavola et al., 2004) STEAM could be seen as focussing on the ethnography of teacher practice, including idiosyncratic interactive modelling (Ritchhart, 2015), liminal states (Land & Meyer, 2005), "troublesome and unsafe journeys" (Meyer & Turner, 2006, p. 374), growth mindsets (Dweck, 2008), and the collective construction of knowledge "leading to the reality of 'innovation' being a label to what we were actually doing" (Paavola et al., 2004, p. 557) Research establishing the importance of creating new knowledge and experiences to solve problems (Taylor, 2016; Wagner, 2012), supports the notion that "what you know is far less important than what you can do with what you know"

(Wagner, 2012, p. 42), foregrounding knowledge through inquiry as collectively powerful in the enactment of innovative transdisciplinarity STEAM learning.

Manifesting a culture of innovation within a school relies on three elements of creativity. According to Amabile (1997), these elements are expertise, creative thinking skills and motivation, driven by curiosity and a desire to enquire. Figure 2.2 demonstrates how Wagner (2012) adapted and revised Amabile's innovation framework to include the constructivist view of the surrounding environment, the culture of the learning environment, it's values, beliefs and behaviours, being deeply influential to "how expertise and creative-thinking skills are acquired and how motivation is developed" (Wagner, 2012, p. 58).

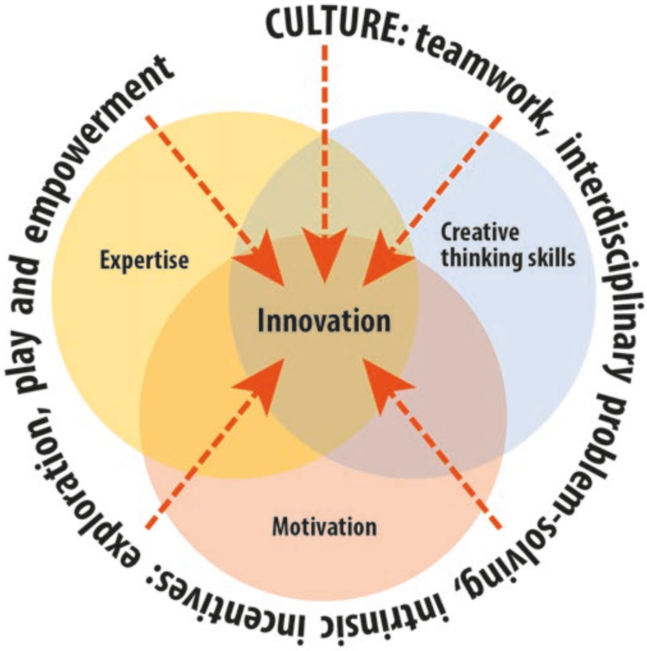


Figure 2.2: Revised framework for developing innovative capacities (Amabile, 1997, in Wagner, 2012, p. 58)

Expanding on Amabile's potentially disruptive interpretation of creativity, is the way Wagner (2012) has viewed motivation to be crucial to the development of innovative education practice:

> Expertise and creative thinking are an individual's raw materials – his or her own natural resources, if you will. But a third factor – motivation – determines what people will actually do. (Wagner, 2012, p. 24)

One could substitute 'transdisciplinary STEAM' for 'innovation' and the framework for developing innovation capacities would remain the same.

2.1.3 Considering STEAM as authentic transdisciplinarity

Authentic transdisciplinarity requires bringing ourselves to our teaching and sharing what we do well as well as where we struggle. Ritchhart (2015) says to the educator: "allow yourself to be authentic. Look for opportunities to share your struggles as a thinker and learner" (Ritchhart, 2015, p. 138). In STEAM professional learning (PL), removing the teacher from a position of absolute authority, requires continual consideration of a teacher's input to a collective culture of thinking, where modelling self-reflection becomes a vehicle to courageous learning.

> If we value being a thinker, we would talk differently as well as changing the way we listen to one another. We would probably pause before responding and take some time to reflect on how effective our interactions are… We would hold ourselves accountable to the same expectations we have of our students. And we would create our own productive struggles to engage in. (Ritchhart, 2015, p. 285)

Such views have epitomised UNESCO's (2017) evaluation of accountability in education. Similarly, Wagner (2012) has considered intrinsic teacher motivation as comprised of more than passion and interest, in that motivation is also fashioned from interrelated elements of play, curiosity, fearlessness, and purpose. Studies related to curiosity (L. Campbell, 2018; Housen, 2002; Manguel, 2015; Soh, 2017) and fearlessness (Bereczkia & Kárpátib, 2018; Schleicher, 2018; Soh, 2017) have offered a very human contribution to learning in STEAM. Curiosity and fearlessness coexist emotionally with explorations of personal and professional identity and agency, self-perceived levels of creativity, and the ambiguous notion of *who owns the learning*? However, the question really being asked of transdisciplinary STEAM is *how can the learning be sustained*? Ritchhart (2015) views the efforts in defining a culture of thinking, as simple as asking the question "Can teachers teach thinking if they are not thinkers themselves?" (p. 284). Transdisciplinarity offers appealing influence for teachers to 'think' laterally and activate the possibility of connecting their thinking in authentic real-world terms, for themselves *and* for their students.

2.2 Activity Emotions

> *Darwin saw every emotion as a predisposition to act in a unique way: fear, to freeze or flee; anger, to fight; joy, to embrace; and so on. Brain imaging studies now show that at the neural level he was right. To feel any emotion stirs the related urge to act. (Goleman, 2006, p. 61)*

Chronicles of the teacher, girl-crushing on her new math curriculum: Week 2, Lesson 1! I was emotional at the end of the lesson. It was by far the best math discussion I've ever had on the first day. (Tweet from @IllustrateMath, 2018)

This section of the literature review weaves a path between innovation attributes and activity emotions, as personal learning attributes emerge dialectically through *felt* experiences. Research in the affective sciences agree that human emotions are coordinated subsystems of mind and behaviour, resulting in a multicomponent system that conveys indefinable subjective impact throughout our entire lives (Pallasmaa, 2016; Schulz & Pekrun, 2007). Situating such multicomponent systems in the context of teacher identity development prescribes experiencing emotions as reflective and relational, influenced by positive *and* negative factors. Above all, "the self of the person stands in the centre of the emotions that are experienced" (Woods & Carlyle, 2002, p. 170).

Face to face interactions between people in learning situations fire multiple parallel neural circuits in each person's brain. "These systems for emotional contagion cause traffic in the entire range of feeling, from sadness and anxiety to joy" (Dweck, 2008, p. 51), adding value to "sentient thinking functions" (Takeuchi, (2010), in Sousa & Pilecki, 2013). The consequent link to action spreads the emotion further. "To feel any emotion stirs the related urge to act" (Goleman, 2006, p. 39), and when we see specific expression of emotions in others, similar neural activity is activated in our own brains (p. 61). Csíkszentmihályí, in *Flow, the Psychology of Optimal Experience* (1990), supports the evidence of contagious neural activity potentially leading to moments of total absorption, or *flow*. What is trying to be achieved through transdisciplinary STEAM learning is increased emotional and intellectual contagion where more people are responsive to the rewards of discovery (Csíkszentmihályí, 1990; Dweck, 2008; Goleman, 2006) and less prone to being frazzled (Arnsten, 1998).

Calling this the 'sweet spot for achievement', Goleman (2006) proposes inspired moments of learning to be "a potent combination of full attention, enthusiastic interest, and positive emotional intensity" (p. 269). Thus, it would be impossible to conduct research on innovative integrated models of STEAM learning without considering emotions as a significant contributor to the learning experience. Using experience sampling to capture some of the teacher emotions was based on the fact that experience sampling methodologies (ESM) "have not been widely harnessed in education research" (Zirkel, Garcia, & Murphy, 2015, p. 7). ESM feeds into the concept, and indeed, the action of play, which in STEAM learning, invites teachers to learn by doing and apply problem-solving approaches to lifelong learning. Therefore, this is where the literature surrounding activity emotions begins, with play.

2.2.1 Play

> *PLAY. It is an activity which proceeds within certain limits of time and space, in a visible order, according to rules freely accepted, and outside the sphere of necessity or material utility. The play-mood is one of rapture and enthusiasm, and is sacred or festive in accordance with the occasion. A feeling of exaltation and tension accompanies the action. Homo Ludens (Huizinga, 1955, p. 132)*

Creativity, measured often through the action of play, is frequently located in the literature adjacent to competencies such as problem solving, collaboration, critical thinking and innovation; a standard position in most agency reports (ACARA, 2014c; Ferris, 2017; Finkel, 2016). The literature has demonstrated how teachers may benefit from the opportunity to understand the subtle nuances of play in terms of learning, proposing that teachers must give themselves permission to play in *their world* as well as the world of their students. Golden (2018) contests that such permission is frequently obstructed within an education environment increasingly overtaken by market driven acronyms and top-down reform. Play is an important STEAM attribute, often requiring a learner to make and fail, and make again.

Congruent with the concept of play being open to toying with ideas and exploring new possibilities, are other more literal interpretations of the word; that is, creating and making, experimenting, trying new ways of ideation, or crafting learning ecologies that foster imagination and creativity (Craft, 2015; Soh, 2017). Play is also a characteristic of material form, say of timber, paper or fabric. In this case play appears synonymous to flexibility, or transformation. Play is not rigid. Wade-Leeuwen (2016) suggests the 'spirit of play' is integral to pre-service teacher training. Play represents a method of spontaneous self-expression influenced by the importance of Vygotsky's (1978) interpretation of interactive learning. Previous research shows how playful capacity-building strategies in conjunction with harnessing the power of visual and creative arts contribute to understanding STEM concepts, suggesting "without toying with possibilities, new ones cannot be opened up" (Craft, 2015, p. 54; Wade-Leeuwen, 2016).

One might say, teachers toying with possibilities is underwritten by granting oneself 'permission to play'.

Hands-on, experiential and imaginative learning are considered paramount to the construction and retention of knowledge (Burnard, Craft, & Grainger, 2006; Soh, 2017). A teacher may prefer using certain creative techniques through the use of different media across arts, mathematics, literature, language, sport and science, according to their level of expertise, training and comfort zone. However the spirit of play, deep play, "is spontaneity, discovery and being open to new challenges" (Ackerman, 2000, p. 38). Campbell (2018) in research exploring the culture of creative professionalism, has suggested teacher agency is made of a type of 'pedagogical bricolage' (p. 3). In this situation, the *bricoleur* searches for practical methods to solve problems making use of available resources or those ready to hand. In STEAM, the teacher *bricoleur* develops strategies, adapts materials and creatively interprets a possible outcome from the "heterogeneous objects of which their treasury is composed" (Levi Strauss, 1966, in L. Campbell, 2018, p. 3). They play; with ideas, materials, tools, and with each other. Through play, it is possible to motivate teachers with low self-efficacy by engaging in collective activity grounded in a high level of coordinated collaboration (Ninkovic & Floric, 2018). Bandura's (1997) social cognitive theory has affirmed "that members of the group judge the group efficacy on the basis of self-assessment of personal abilities" (p. 53). This would imply that for teachers to explore their pedagogical treasury and to play around with ideas requires choice as well as freedom (Ackerman, 2000). "Freedom alone doesn't ensure a playful result; people often choose the work they do, and not everyone is lucky enough to regard their work as play" (p. 7). Conversely, play might be regarded as simply make-believe situations, inventing substitute worlds, creating 'what if' scenarios. Paradoxically, Craft's (2015) research has identified play through the same lens as possibility thinking, simply considering playfulness to be a key feature of an inclusive learning environment. Craft (2015) has suggested the playfulness of teachers may be enacted via finding inventive and flexible ways of applying their philosophies and methodologies into learning contexts.

Viewed from a Visual Arts and Design perspective, *play* in the traditional sense of the word might be considered drawing, sketching, sculpting, designing and making.

Such forms of visual representation are equally useful in solving mathematical problems. Yakman (2008) has informed us that mathematical modelling is used in a variety of playful tangible scenarios that describe and analyse situations enabling understanding of how STEM is applied in the real world. Viewed from the Arts perspectives, specifically visual arts, design, dance, drama and music, modelling STEM concepts can also be achieved by embodiment, use of space, movement and a wide range of materials and tools, including ICT (Bereczkia & Kárpátib, 2018; Fenyvesi et al., 2020). Play is not dependent on dedicated STEAM learning environments, yet is most often dependent on integrating the personal abilities of a group.

One of the determinants in defining play is trying new ways of doing something, currently heavily promoted in education innovation literature (Tait & Faulkner, 2016; Craft, 2015). "Our culture thrives on play' (Ackerman, 2000, p. 4). Play assists ways of knowing more than just knowledge of how to demonstrate abstract ideas, mimic situations or represent physical objects. Playing supplies the capacity to understand how things work together, how systems operate to achieve their purpose (Campbell & Jobling, 2012). Ackerman (2000) has declared "ideas are playful reverberations of the mind" and together with collaborative reasoning, play can be acknowledged as a tacit system (p. 47). Tacit knowledge applied in STEAM contexts, is understanding how interdisciplinary components work together to achieve a purpose, solve a problem or address an issue. Playing and making encourage the development of critical thinking skills and Maeda's (2012) call for makers to broadcast their proficiencies in problem-solving, fearlessness and critical thinking replicates the demand for deep play in learning.

The product of deep play in STEAM is generally perceived to be the visible artefact. However, STEAM learning may also be visceral. Ackerman (2000) has said "deep play is the ecstatic form of play" (p. 12), and at its peak, all elements are visible and intense. Not unlike the personal aesthetic experience valued by Hirsh-Pasek, Zosh, Michnick Golinkoff ,Gray, Robb, & Kaufman, (2015), Robinson (2010), and Csíkszentmihályí (1990), as an experience of *flow*, in which a person loses a sense of time while completely engaged in an activity. "Thus, deep play should really be classified by mood, not activity. It testifies to *how* something happens, not *what* happens" (Ackerman, 2000, p. 12). The idea of *how something happens* suggests that the action of learning in STEAM far outweighs the output of the physical/virtual product. The literature on play has foregrounded exploration and discovery as central to the notion of play. To be swept up in a deep state of play, immersed, engaged, oblivious to the surrounding environment, incites feelings of balance, focus, creativity, challenge and possibility (Ackerman, 2000; Burnard et al., 2018; Craft, 2015; Holdener, 2016). Finding oneself immersed in STEAM learning may depend on maintaining curiosity and perseverance, with acute awareness of how these states are embodied as *feelings*.

2.2.2 Curiosity

> *I can appreciate the beauty of a flower. At the same time, I see much more about the flower that he sees. I could imagine the cells in there, the complicated actions inside which also have a beauty. I mean, it's not just beauty at this dimension of one centimeter: there is also beauty at a smaller dimension, the inner structure... also the processes. The fact that the colors in the flower are evolved in order to attract insects to pollinate it is interesting - it means that insects can see the color. It adds a question - does this aesthetic sense also exist in the lower forms that are... why is it aesthetic, all kinds of interesting questions which a science knowledge only adds to the excitement and mystery and the awe of a flower. It only adds. I don't understand how it subtracts. (Feynman, in the Pleasure of Finding Things Out, 1981)*

Acknowledged from a scientific perspective, 1965 Physics Nobel Laureate, Richard Feynman, has proposed curiosity lies at the core of intrinsic learning. Curiosity asks "why" then really "why?" (Anderson & Jefferson, 2016, p. 161). Similarly, Manguel (2015) has asked "perhaps all curiosity can be summed up in Michael de Montaigne's famous question "Que sais-je?": What do I know?" (p. 2). The question of course is derived from the Socratic *Know thyself,* but Manguel suggests,

> It becomes not an existentialist assertion of the need to know who we are but rather a continuous state of questioning of the territory through which our mind is advancing (or has already advanced) and of the uncharted country ahead. (Manguel, 2015, p. 2)

In similar literature, Ritchhart (2015) has asked educators to share curiosity moments, affirming that "curiosity is a highly valued disposition as a driver of new learning" (p. 138), while Rahm (2016) views shared conversations and personal comments as meaningful activators of peer curiosity, blending learning with other life contexts.

Studies investigating the idea or concept of curiosity from the perspective of emotions felt during STEAM learning, have revealed critical imbricating ideas related to creativity, perseverance and the action of risk taking (Duckworth, 2016; Goodwin, 2012; Timm, Mosquera, & Stobäus, 2016). Goodwin (2012) has suggested problem finding, in addition to problem solving, is characterised by insight, vision, curiosity and challenge, while simultaneously posing risk, stirring feelings of anxiety and doubt. While curiosity might be considered a child-centred action, to be curious is presented as extremely useful in co-creating opportunities to learn in STEAM settings. Bequette and Bequette (2012) have promoted curiosity as a key disposition of both artists *and* scientists. Encouraging creative classroom ecology however, may be dependent on teachers embracing their own curiosity and modelling the way such curiosity manifests in all its forms.

Considering balanced transdisciplinary approaches to learning, educational philosopher John Dewey's (1938) emphasis on the scientific nature of curious and keen observation to determine meaning in art, sees potential transference to STEAM. Integrated education research has attempted to meld the transfer potential between foregrounding maths and science practices, to the development of critical capacities through art (Glass & Wilson, 2016; Housen, 2002). Such capacities are attainable "when it is framed with the right kind of pedagogical process" (Housen, 2002, p. 121). Transdisciplinary learning environments aim to create a place to think and be curious. STEAM locates *making* the artefact, whether visual, performative or time based, in a composite experience within which all questions bind (Manguel, 2015), and where "affirmations tend to isolate" (p. 2). Congruent with French philosopher Simone Wiel's views on culture, Manguel, in *Curiosity* (2015), has primed us to perceive STEAM as "the formation of attention" (p. 50) or, a place to think. Manguel (2015) has positioned teachers as those who can:

> …help students discover unknown territories, provide them with specialised information, help create for themselves an intellectual discipline, but above all, he or she must establish for them a place of mental freedom in which they can exercise their imagination and their curiosity, a place in which they can learn to think. (Manguel, 2015, p. 50)

STEAM offers dual conditions to think *and* to make. Thinking made visible, or *visible thinking*, Harvard's framework aimed at developing thinking skills and characteristics related to deep learning (Kalbstein, 2015), "includes but is not limited to curiosity, creativity and being skilled at, alert to and eager to take thinking and learning opportunities" (Kalbstein, 2015, p. 29). Pedagogical skills that support making as knowledge building include providing opportunities for teachers to experience innovative learning activities alongside their students (Vossoughi, Hooper, & Escudé, 2016). There is much transferral of knowledge between domains when physical activity is combined with theoretical content in STEAM.

Questioning how and why a task is to be done frequently requires an algorithmic, or step by step approach (Sterling, 2015), regularly employing analogue tools such as pencil and paper to solve problems (Freeman et al., 2015). The computational thinking perspective of *expressing* begins with curiosity before embedding itself within the language of visible thinking. Sterling (2015) has suggested algorithmic thinking pertains to creating and making:

> The computational thinking perspective of 'questioning', which entails questioning the world, connects seamlessly with the visible thinking move of wondering and asking questions as well as the link between questioning and curiosity and learning. (Sterling, 2015, p. 29)

Bricolage, or intermixed traits inherent in STEAM learning warrant curiosity to be expressed through the ability to think and communicate as part of a team, handle uncertainty, unfold experience based on inquiry, and tolerate ambiguity without losing sight of the big picture (Bequette & Bequette, 2012; Housen, 2002; Soh, 2017). Campbell's (2018) suggestion of visualising teacher professionalism as bricolage, made up of diverse talents and experience, asks that the artisan quality of teachers' practice be reframed as agents of creative and transformative learning, driven by curiosity. In contrast to curiosity, predictability is less emotionally labour intensive. Predictability saves energy (Eagleman & Brandt, 2017). There is appeal in predictability and repetition.

The existence of predictability in schools exposes the reality that teachers and their leaders face many issues and shifting priorities, and face constant pressure from community, political timing, research reports and tertiary agencies (Tait & Faulkner, 2016). Finding direct correlation between innovative or transformational learning frameworks and the factors affecting change in schools requires viewing knowledge creation as purposefully curious, integrative, collective *and* individual. Koeslag-Kreunun et al. (2017) have defined innovative tasks as "highly novel, complex, and low-structured" (p. 192). Such research has placed importance on the combination of multiple inputs and developing ownership of the design, implementation and evaluation of innovative educational development, characterised by professional interdependence and shared responsibility (Koeslag-Kreunen, Klink, Bossche, & Gijselaers, 2017).

Adopting curiosity as collaborative transdisciplinary practice serves to address the social, economic, technological and environmental demand to increase teachers' creative capacity by generating novelty, surprise, interconnected knowledge and acceptance of change (Eagleman & Brandt, 2017; Koeslag-Kreunen et al., 2017; Schleicher, 2018). Drawn from epistemological and ontological comparisons, STEAM learning is at best, embodied curiosity, enacting both algorithmic and serendipitous methods of learning and being. Bereczkia & Kárpátib (2018) have viewed curiosity as *divergence*. And divergent pedagogy requires passion and fearlessness.

2.2.3 Passion

> *Mathematics which comes from the inside while at the same time describing something on the outside, is the only science in which one is able to find the truth… by looking inside oneself. (Zagier, 2011, pp. 96-97)*

The truth described by Zagier in *A Passion for Mathematics* (2011) may well describe the discovery moments experienced in STEAM learning. Similar sentiment may also describe the methods used to manufacture an environment where people are comfortable being creative (Tait & Faulkner, 2016). Using Eisner's (2006) argument that if the notion of artistic intelligences is to be taken seriously, the concept of understanding mathematics might be considered in the same light. The literature related to transdisciplinarity has found passion to be expressed as a desire for mastery, to explore novel ideas, learn something new, and understand something more deeply (Ruiz-Alfonso & Leon, 2016; Vallerand, 2015; Wagner, 2012). The sensation of passion in terms of play and purpose, according to Ackerman (2000), renders it difficult not to brood, not to extrapolate, not to analyse, not to cling to some *thing* when we think. When we are passionate about discovering something new, the novelty, by virtue of its nature of newness, is exciting.

> Our basic curiosity, as well as our passion for mysteries, exploration, and adventure may spring from the orienting reflex, the body's mindless response to novelty or change. (Ackerman, 2000, p. 93).

Previous studies have suggested *perseverance* as key contributor to the notion of passion as motivator. In more than one hundred and fifty interviews for his book *Creating Innovators*, Wagner (2012) identifies that passion was the most frequently recurring word. Passion is also related to self-identity and self-belief, demonstrated in how one behaves and how one teaches with a view to adding value to the lives of students (Vallerand, 2015). Vallerand's (2015) research has positioned passion in the education lexicon as a conduit to job satisfaction, positive attitudes towards pedagogical context, possibilities for enhanced collaboration and the maintenance of strong collegial connections. It has been noticed that such connections, in turn, influence student academic performance and school experience (Phelps & Benson, 2012), frequently expressed through emotions.

The literature has expressed "Epistemic emotions are emotions triggered by cognitive problems" (Pekrun, 2014, p. 8). Feeling surprise about a new task, being curious, or confused and frustrated are all elements of experiencing epistemic emotions, usually culminating in delight when the problem is solved. Haptic sensations are often relegated to a secondary reactive or emotional perception (Fiorilli, Gabola, Pepe, Maylan, Curchod-Ruedi, Albanese, & Doudin, 2015; Liu, Song, & Miao, 2018). Yet the importance of feeling and mood, identified as haptic sensations by Fiorilli et al. (2015), are immediately identifiable in STEAM learning, particularly in situations where thinking hands (Pallasmaa, 2009), meet *productive persistence*. The combination of passion and persistence is considered to be extremely valuable in predicting individual success and increased professional self-efficacy (Duckworth, 2016; Sousa & Pilecki, 2013). Synonymous with grit, perseverance, according to Duckworth (2016), is measurable. Duckworth has developed a scale to measure an individual's grit, finding that grit, or perseverance, can offset talent in that those with high levels of perseverance but self-perceived average talent can achieve greater creative success than those with self-perceived high talent and little grit. "That is because the latter tend to give up when faced with obstacles while the former persevere to finish the task" (in Sousa & Pilecki, 2013, p. 154). STEAM learning topologically stretches such passionate philosophies and beliefs. Hence the developmental, innovative and transformational aspects of STEAM learning may be seen as a social process focused on phenomena over time, including mapping ways in which people experience (Marton, 1988; Pressick-Kilborn, Sainsbury, & Walker, 2005). Hattie (2012) has related the notion of passion to the demonstration of apparent care and commitment to peers and students, reminding us that we are all learners and we are all human. And the literature has stressed that to innovate is human (Pink, 2018; Wagner, 2012). However, to innovate in education is not easy. Wagner (2012) has agreed with Pink's (2009) comments that passion alone, cannot sustain the motivation and perseverance to do difficult things, proposing "the importance of autonomy, mastery, and purpose as essential human motivations" (Wagner, 2012, p. 29). Passion is *felt*. It is driven by emotions and is for the best part, fleeting.

Two types of passion proposed by Vallerand (2015) are evident in education settings: harmonious passion, where people participate in an activity because they believe the activity to be consistent with their values and intentions; and obsessive passion, a controlled internalised passion originating from external pressure (Vallerand, 2015). The dualistic model of passion defined by Vallerand (2015) is "a strong inclination toward a self-defining activity that one likes (or loves), finds important, and in which one invests a significant amount of time and energy" (p. 174). Harmonious passion, as the label suggests, affects the individual in terms of autonomy, freedom and experience aligned with choices made in life; while obsessive passion, conversely, is controlled less by choice and more by the social environment comprised of external factors related to feelings of self-esteem or social acceptance. Further evaluation of passion in the literature has exposed that "when teachers perceive the powerful effect they have on their pupils, their sense of passion persists" (Ruiz-Alfonso & Leon, 2016, p. 184). Innervating contemporary STEM and STEAM learning, may generate situations where the dualistic nature of passion is fervently exposed. Bonneville-Roussy, Vallerand, & Bouffard, (2013) have observed that students who perceived their teachers as collectively passionate and autonomy supportive, experienced similar positive emotions, flow or concentration, influencing both teacher and student subjective well-being and life satisfaction. The same study showed barriers to sustaining teacher passion were primarily recorded as *time*. That is, time spent engaged in administrative "paperwork" tasks (Phelps & Benson, 2012, p. 72). Nevertheless, energy-intensive curriculum development views the dualistic nature of passion as potentially empowering, motivating STEAM teachers to engage with a certain level of fearlessness.

2.2.4 Fearlessness

> *What gives value to travel is fear. It is the fact that at a certain moment, when we are so far from our own country… we are seized by a vague fear, and an instinctive desire to go back to the protection of old habits…. At that moment, we are feverish but also porous, so that the slightest touch makes us quiver to the depths of our being. We come across a cascade of light, and there is eternity. (Albert Camus in Notebooks, 1935-1942, 1996, pp. 13-14)*

Such poetic description of the psychological effects of fearlessness provides a metaphor for STEAM learning. Palmer (1998) has viewed fear as enhancing education, where it is possible to acknowledge that fear "makes people porous to real learning" (1998, p. 39), and reminds us that it is important to remember that fear can be healthy. "Some fears can help us survive, even learn and grow – if we know how to decode them" (Palmer, 1998, p. 39). In *the Courage to Teach*, Palmer has reframed teachers' personal and public fear as an insightful positive force, and proposes *insight* as the dominant norm rather than specific training, structural reform or acceptance (of fear). Palmer has argued that insight can release the pathological fears inherent in most human lives. Interestingly, insight through *play* is also possible: "One can create mildly. One can live at a low flame. Most people do. We're afraid to look foolish, or feel too extravagantly, or make a mistake" (Ackerman, 2000, p. 196). Conversely, May (1975), in *The Courage to Create*, has suggested creativity incites anxiety, felt as disorientation or "temporary rootlessness" (p. 93). May (1975) in scholarly work related to the nature of creativity, has wedded the notion of ecstasy with anxiety. May has used Maslow's description of ecstasy as 'peak experience', and anxiety as 'the fear and trembling' of people in their moments of creative encounter. Fundamentally, Palmer (1998) and May (1975) have agreed that fear is closely linked to identity.

Other studies in this area have found that teachers' experiences are modulated through conscious goal-directed thoughts, emotion and action, swerving directly into iterative paths characterised by deliberate self-regulation, reflection and reaction (Zelazo, 2015). When travelled, such paths require liberation from fear. Fear impacts a person's sense of self (Kahneman, 2011; Tait & Faulkner, 2016). Fear of failure parallels the notion of a fixed mindset (Dweck, 2008). The key element to achieving a successful common objective set by the criteria based collaborative challenge, is active information sharing and releasing the fear of failure (Romero, Hyvönen, & Barberà, 2012). 'I can't' is a perceived response based on engagement with negative suggestions, often made by the self (Maltz, 2015). Countering fear, Dweck has argued that a growth mindset would allow a person the "luxury of becoming" (Dweck, 2008, p. 25), or in the words of Greene (in Pinar, 1998), "I am…not yet" (p. 81).

In the context of STEAM education, fear can be viewed as encounters that challenge and "enlarge our thinking, our identity, our lives – the fear that lets us know we are on the brink of real learning" (Palmer, 1998, p. 39). In discourse related to the vocation of teaching, Schleicher (2018) OECD Director for Education, has supported fearlessness in the development of an informed profession, encouraging abandonment of former prescriptive behaviours. In efforts to scale up innovation in education, collaborative working norms might "replace the industrial work organisation, with its administrative control and accountability" (Schleicher, 2018, p. 3). Certainly a new sense of professionalism, one that embraces risk, change and the anxiety accompanying "a world not as we experienced it before" (May, 1975, p. 93) exists in STEAM learning.

STEAM curricula requires collaborators to embrace a level of fearlessness when facing a dive into the deep end of learning (Wagner, 2012). Creative educators, in the face of unidentified efficacious qualities are able to live with the anxiety of change (May, 1975) and perhaps undertake personal risks to play, invite whimsy and organised chaos into their learning and teaching. In this way, they are encouraged to accept a correlated version of themselves, no longer what they were before, activating what May (1975) has described as "past, present and future to form a new Gestalt" (p. 93). While simultaneously, as Wagner (2012) has indicated, it is important to be having fun. Learners having fun are characteristically operating by intrinsic motivation. Wagner's interpretation of whimsy in innovation has incorporated the "intrinsic incentives of exploration, empowerment, and play" (p. 57), further purporting that the academic content of a whimsical experience must be learning in context.

In research specifically focussed on STEAM, McAuliffe (2016) has considered content co-creation is vital. Input from various disciplines with focus on strategic, balanced teamwork may produce PL situations in which fear is no longer impervious but porous. Both Palmer (1998) and May (1971) have considered that porosity enhances connectedness and translates potential failure as a way to learn and grow. Porosity presents "new meaning, new forms, and discloses a reality that was literally not present before, a reality that is not merely subjective but has a second pole which is outside ourselves" (May, 1975, p. 91). In the same vein, 'whimsy' may not be the *absolute* adjective, yet a proportion of whimsical play is vital to achieving the desired outcome in STEAM. Support from the literature has speculated that what is really being defined here is STEAM *culture*. Co-creation, in terms of professional relevance, notwithstanding the demands of the system, requires serious traits of resilience, resourcefulness, confidence, self-efficacy, capacity and motivation (L. Campbell, 2018; Lemon & Garvis, 2015; Ninkovic & Floric, 2018).

Describing critical moments for learning among teachers, Brody and Hadar (2018) have referred to the concept of change in the psychological sense that sees change as dynamic transition replete with many achievement goals in relation to professional development of in-service and pre-service teachers. Similarly, Schunk (2011) has applied self-efficacy theory to propose that personal accomplishments, vicarious experiences and types of persuasion are included in methods of personal self-appraisal and "once a strong sense of efficacy is developed, a failure may not have much impact" (p. 208). However, it is the inter and transdisciplinary disruption, driven by evolving pedagogy and technologies, evident in current education systems that makes it possible for fearless teachers to take risks and encourage the emergence of new ideas (Schleicher, 2018; Tait & Faulkner, 2016; Wagner, 2012).

Considering STEAM as a current trend in education, it is apt to accept that "many theorists believe that the current trends in school reforms call for a leader with transformational abilities" (Ninkovic & Floric, 2018, p. 51). Teacher PL and positive circumstantial elements associated with collective teacher efficacy, find the responsibility of the fearless school leader to be one that permits teachers to play, adapt to change and gain a sense of professional wellbeing (Liu et al., 2018; Ninkovic & Floric, 2018). Motivation to change may also start small. Tait and Faulkner (2016) raised the idea of *small* being important in a "play by play" approach to "unleashing great ideas in [your] school" (p. 15). Such studies suggest reducing complexity to make change, citing Schumacher: "Any intelligent fool can make things bigger, more complex and more violent. It takes a touch of genius – and a lot of courage to move in the opposite direction" (Tait & Faulkner, 2016, p. 9). Likewise, research led by Craft et al. (2006; 2015; 2012) has espoused fearlessness as the inspiration that allows us to transform *what is* into *what might be*. Burnard (2006) has promoted Craft's positioning of the question 'what if?' through 'possibility thinking' (PT):

> 'what if?' together with perspective taking and 'as if' thinking. [Craft] argued that PT was evidenced in the shift from 'what is' to 'what might be' and that this might involve questioning, imagination and play (Craft, 2000, 2001, 2002).

Fittingly, 'what if' we encourage teachers as well as students to find out more about themselves via authorised STEAM collaborations in Australian secondary school settings? Thus transforming STEAM from an education trend to relatable life-learning experiences with high possibility.

Previous research introducing the concept of 'possibility thinking' has provided much evidence of enhanced learning outcomes for teachers and students (Burnard et al., 2006; Hunter, 2015). Framed as *High Possibility Classrooms* (HPC) and appreciably underpinned by technology integration, it is interesting to note that HPC concepts have supplied potent force in teachers' STEM and STEAM knowledge (Hunter, 2015). Encouraging teacher creativity, unleashing playful moments, supporting differentiated values, enablement and engagement with external audiences to showcase how the teachers and students learn, forms a major part of engagement in possibility thinking (Burnard et al., 2006; Hunter, 2015). Reframing possibility thinking as fearless STEAM pedagogy, aspects of this model are disrupted by the elements of risk, play and surprise. In like manner, such is the nature of STEAM education when supported by leaders and teachers who are not afraid to make a mistake, or risk unnecessary pain. These are the educators who choose to reject the act of teaching as "an exercise in moderation" (Ackerman, 2000, p. 196). These are the fearless. They teach with purpose.

2.2.5 Purpose

> *Purpose in the human being is a much more complex phenomenon than what used to be called will power. Purpose involves all levels of experience. We cannot* will *to have insights. We cannot* will *creativity. But we can* will *to give ourselves to the encounter with intensity of dedication and commitment. The deeper aspects of awareness are activated to the extent that the person is committed to the encounter. (May, 1975, p. 46)*

A growing body of literature has investigated the challenging and conflicting demands of learning ethnographies that provide professional experiences steeped in purposeful personal integration (e.g. Craft, 2015; Golden, 2018; Keane & Cimino, 2019; McAuliffe, 2016; Wagner, 2012). The way in which positioning self-belief far from the individualistic technicist view of teaching was studied by Campbell (2018) and Lemon and Garvis (2015) in particular. Campbell (2018) views teachers as 'extended professionals', continually faced with defying conservatism and finding new depth in teaching practice. The learning continuum operating throughout the teacher's career correlates with the development of attitudes and values that move them and their students beyond "concerns with technique and survival, towards constant reconceptualisation of the profession" (L. Campbell, 2018, p. 6).

A growing body of literature has investigated the challenging and conflicting demands of learning ethnographies that provide professional experiences steeped in purposeful personal integration (e.g. Craft, 2015; Golden, 2018; Keane & Cimino, 2019; McAuliffe, 2016; Wagner, 2012). Professional growth, visible in many teacher narratives, results from "interaction and negotiation of meaning within the community, and from effects of implicit or explicit messages received from students and colleagues" (Brody & Hadar, 2018, p. 61). Much research related to growing 21st century skills has promoted a transformed pedagogical environment organised around interrelated motivational elements including play, curiosity, passion, fearlessness and purpose (Craft, 2015; Golden, 2018; Wagner, 2012). Purpose requires commitment to evolve, to change; and in education, change, as an imperative, may be viewed as a collective responsibility. Many studies in education and psychology research have found that change is perceived to be the product of cumulative individual journeys, stimulated by a person's internal desire to do something different, seek surprise or novelty (Brody & Hadar, 2018; Eagleman & Brandt, 2017; Wagner, 2012). Wagner's innovation research has revealed that the sense of purpose most frequently emerging is "the desire to somehow 'make a difference'" (Wagner, 2012, p. 29). How often have we as teachers, heard this desire or offered it as our own singular motivation for entering the profession and developing our practice? Eagleman and Brandt (2017) have offered a broad synergistic view of innovation in the human sense, appreciating the desire to innovate, in essence, is the human requirement to rework and keep changing, begging the question: "Why can't we find the perfect solution and stick with it?" (p. 4). The answer: "innovation will never stop. It's never about the *right* thing; it's about the *next* thing" (Eagleman & Brandt, 2017, p. 4).

How do educators know what the next thing is? In terms of education, the need for unified cultivation of human capabilities has been widely broadcast, in direct response to the challenges of the 21st century outlined in Australian Curricula – "with its complex environmental, social and economic pressures – [requiring] young people to be creative, innovative, enterprising and adaptable, with the motivation, confidence and skills to use critical and creative thinking purposefully" (ACARA, 2014c, p. 250). Consistent with international research outlined in the National STEM School Education Strategy 2016 – 2026, commissioned by the National Education Council of Australia, "industry surveys show that STEM literacy is increasingly becoming part of the core capabilities that Australian employers need" (p.4). Transdisciplinary experiences may address the need for teachers to flexibly navigate a global response to STEM innovation agendas. Contrary to Eagleman and Brandt's (2017) understanding of humans' desire to innovate, some neoliberalist narratives have framed teachers in industrialised nations (such as Australia) as flexible technicians (Golden, 2018). Such flexible technicians disrupt longstanding perceptions of teachers' roles as somewhat conservative authoritarian deliverers of information, choosing instead the pursuit of pedagogical practice that fosters teachers' ability to creatively connect concepts. Such practice engenders the state of *promisingness*, creative activity determined by Koestler (1967) to be "a type of learning process where teacher and pupil are one" (p. 23).

Research evaluating the role of creativity in STEM has revealed a range of phenomenological evidence supporting the view that teachers see personal life creativity as strongly associated with creativity in teaching, *and* teaching for creativity (Henriksen & Mishra, 2015; Merriman, 2015, in Bereczkia & Kárpátib, 2018). Thus rather than determining beliefs about pedagogy through a lens of personal likes and dislikes, (Kahneman, 2011), teacher purpose in relation to transdisciplinary STEAM must acknowledge the critical link between what Kahneman has termed 'System 1' and 'System 2' thinking. System 2 is active in "deliberate memory search, complex computations, comparisons, planning, and choice" (Kahneman, 2011, p. 103), and System 1 is related to intuition. Both systems are connected through purposeful action or the act of making an effort, ultimately rendering creativity as both expressions of cognitive ease *and* cognitive strain. Of course, the intention of STEAM is to provide a different perception of learning and knowing (Roth, 1998). Participatory learning in order to augment teacher agency represents Roth's fundamental concern with effective communities of practice. The pleasure of cognitive ease (Kahneman, 2011, p. 65) is associated with good feelings, whereas effort and strain can be observed as emotions displayed by facial expressions and body language. The language of cognitive strain may also benefit from intentional divergent thinking.

It has been stated that synergetic STEAM curriculum content encourages authentic cross-disciplinary fertilisation, encouraging curiosity, experimentation and risk-taking, thus engendering key dispositions of divergent thinking (McAuliffe, 2016).

However, there is also a place for convergent processes in validating STEAM content to avoid a 'ticking boxes' approach. If STEAM learning experiences manufacture success and applause, it is a by-product of the good teaching that charts the inner landscape of the collaborating teachers' lives (Palmer, 1997). Acknowledging collaborative intention and capacity for connectedness, STEAM learning and teaching defends the purpose of innovative pedagogical labours. The by-product of which may shift teacher professional and personal identity, reinforcing Boaler and Dweck's (2016) notion that a growth mindset doesn't always need confidence. Teachers collectively learning something new will influence others around them, and their emotional contagion demonstrates "even when you think you're not good at something, you can still plunge into it wholeheartedly and stick to it" (Dweck, 2008, p. 53).

Interweaving empiricism to measuring the impact of activity emotions in STEAM learning, the literature has frequently returned to the notion of risk. Pallasmaa (2009) calls this "workmanship at risk", implying "the mental uncertainty of advancing on untrodden paths directed to one's self identity, own persona, values, beliefs and ambitions" (Pye, in Pallasmaa, 2009, p. 72). Pallasmaa's research has shown similar implications describe the creative thinking process. Such processes generate data from a variety of different sets, springing from "the innate human survival faculty for sensing and discerning similarities across all domains of an individual's empirical emotional and intellectual experience" (p. 72). Other studies have found sensing and discerning similarities are the foundations of the creative process, culminating in skills of *noticing* and *asking why* (Anderson & Jefferson, 2016) as. Some would express such processes as curiosity. However, the actions of creative and critical thinking, key elements of contemporary learning and teaching, are often undermined by fear, acutely felt in situations in which the learners are adults (Gross-Loh, 2016; Kolb, 1984). Therefore, introducing change to an educational system requires finding and building your champions, the fearless. These are the people "who become raving fans of your idea and lobby for you. They have the keys to the gate and know who you need to talk to. Find these champions and thrill them" (Tait & Faulkner, 2016, p. 134). These are the teachers who understand risk, measure the impact of emotional energy, and endorse the purpose of transdisciplinary STEAM learning through activating a growth mindset.

2.3 Connected pedagogy and curricula

Given that STEAM is an acronym representing input from a range of discipline sources, it is important for teachers to play with ideas, speculate, fail and iterate in order to experience authentic collaboration. Such collaboration necessitates shifts in teacher identity and agency, as teachers position themselves outside their comfort zones, working at the edge of their competence (Dweck, 2008; Keane & Keane, 2016). Such continuous effort must be exerted for educators to move beyond current levels of accomplishment and provide evidence of connecting transdisciplinary practice with policy hidden in curriculum agendas. This section of the literature explores research related to teacher identity and agency, and identifies how the transdisciplinary nature of STEAM learning is connected with a variety of transdisciplinary pedagogical models implemented locally and globally.

2.3.1 STEAM connections with pedagogy through teacher identity and agency

Identity can be said to be constantly reconstructing, adapting and evolving (den-Brok, Taconis, & Fisher, 2010; Krause, Bochner, & Duchesne, 2003). Teacher identity has been noted by Carlone and Johnson (2007) as the in-between concept that connects a person to an environment or context within which a person recognises him/her self and gets recognised as a type, a 'science person' for example. For Kessels and Taconis (2012), identity is composed of values and norms, ways of seeing, knowledge of the self, including ways of knowing, and ways of doing. Craft (2015) notes that "what is of interest here is the notion of multiple selves, of which the transcendent and rational is simply one" (p. 84). Similarly, Palmer (1997) directly links a form of 'transcendent self' with the notion of identity, defining identity as "the irreducible mystery of being human" (p. 5). Acknowledging the teacher as a person *and* a professional defends the inseparability of personal development and life history. Studies related to the demands of the teaching profession (e.g. Sahlberg (2010), Schleicher (2018), Schulz and Pekrun (2007), Timm, Mosquera, and Stobäus (2016), Woods and Carlyle (2002)) have argued that while the teaching profession demands creativity and flexibility, the identity passage navigated within these demands may produce extreme, profound and unsettling emotions experienced in the face of performativity, accountability and skill intensification. Other studies have found a structural tension between teachers' feelings of obligation and guilt related to the endurance nature of the profession emerges when such feelings collide with the desire for inventive flexibility (Craft, 2015; Woods & Carlyle, 2002). Inventive flexibility has been noted in education research as operational in all aspects of teaching's every day actions, in order to provide the necessary human environment to keep the hands and mind busy (Leader, 2016; Craft, 2015). It could be said that inventive flexibility embodies commitment to risk. And as stated previously, STEAM involves pedagogical risk.

A number of studies have made continual and implicit assessment of how transdisciplinary STEM and Arts connection shapes the development of teachers' personal and professional identity (English, 2016; Lemon & Garvis, 2015; McAuliffe, 2016). Such integration strategies are important for 'learning by doing' experiences for current and pre-service teacher education (Hunter, 2015). Congruently, teachers who co-construct shared understandings through collaboration, contribute quality diverse cognitive resources to STEAM contexts. Thus affording the emergence of a sense of wellbeing and belonging as well as creating a wealth of collective knowledge interactions so important to both 21st and 22nd century skills (Santone, 2019; Tomlin, 2018).

The literature related to creativit(ies) (Burnard & Colucci-Gray, 2020) in STEAM education has shown the actions of being creative to be a cooperative composition of interaction amongst knowledge domains, fields and persons (Csikszentmihalyi, 1996; Ingold, 2020). Glăveanu (2019) views the cultivation of creativity as building common ground within a socio-cultural phenomenon. Vygotsky (1978) has recognised creative learning to be a collaborative effort, a socio-cultural experience. Moreover, Vygotsky views learning as a connected social activity; problem solving with more capable peers, and any act, idea or product that leads to the transformation of an existing domain into a new one is considered to be creative. Identity therefore, and in particular, the identity of a teacher, is permeated by the construction of senses and meanings gleaned from experiences assembled from the personal, professional and environmental arena (Krause et al., 2003; Timm et al., 2016).

The perceived emergency in relation to dismantling the industrial education system means that teachers are told repeatedly that education needs to change (Tait & Faulkner, 2016; Robinson, 2010; Timm et al., 2016). Reiterating Wagner's (2012) question: “Where do we start as parents, teachers, mentors and employers?” (p. 23), Vover (2018), Bell (2017), and Tait & Faulkner (2016) propose it is important to consider not only *where* but *how* teachers, including method specific high school teachers, strive for such enablement. Peer coaching as a professional learning structure presents a broad range of activities in which co-planning, co-delivering, co-analysis and co-reflection, foster collective efficacy, recognising the fact that efficacy is also “increased through vicarious experience – when witnessing someone, facing similar circumstances, meeting with success” (Donohoo, 2017, p. 64). Much research identifies that teachers prefer collaborative peer-to peer learning over professional development delivered by outside experts (Beauchamp, Klassen, Parsons, Durkson, & Taylor, 2014). STEAM learning then becomes an internal ecological approach to teacher agency, merging with Craft’s (2015) notion of ‘wise creativity’. Craft describes the humanising nature of creativity as “the relationship between the creator’s identity and their creativity [i.e. that as they are making, they are also being made themselves]” (Craft, 2015, p. xxii). Therefore, teacher agency cannot be actuated without possession of three temporal dimensions: past experience, future goal setting with ability to see possibilities, and affordances given present existing resources, constraints and judgements (Priestly, 2015). Teacher agency stems from pragmatic Deweyan contexts, in that responses are shaped by exposure to problematic situations requiring innovative responses (Biesta, Priestley, & Robinson, 2015). In STEAM, teacher identity is constructed of intertwined elements of wise creativity, responsibility and connection to the wider good, thereby addressing life’s needs (Craft, 2015; Edwards, 2015; Soh, 2017).

Existing research connecting STEM and Arts opportunities for leaders in government, industry, education and social administration have demonstrated what curious educators have known all along: “the arts are integral and life-giving to the process of learning and the art of living” (Sousa & Pilecki, 2013, p. 154). Eagleman (2018) informs us that the arts and sciences are naturally woven together like creative software in our brains. Eagleman explains how this creative software makes humans restless and that’s what compels us to keep inventing (Eagleman, 2018). The connection between neuroscience and education is a growing field of research that explores beyond the simple assumption of learning by doing. The ‘maximal harmonious’ experiences, investigated by Damasio and Goleman (2006), Csíkszentmihályí (1990), and presented as ‘immersion’ by Holdener (2016) and the ‘aesthetic experience’ by Robinson (2010), are presently supported by psychological trends and developments in neuroscience. Neuroplasticity, (the way a brain changes when undertaking certain functions), the development of memory, and perceptual learning are pertinent research areas of neuroscience in relation to the way humans construct and retain knowledge. Dweck’s (2008) fixed mindset versus growth mindset, Pallasmaa’s (2009) essential existential knowledge, and brain compatible strategies explored by Sousa and Pilecki (2013), play a combinatorial role in understanding the way STEAM can be presented as a series of innovative learning experiences for both teachers and students.

2.3.2 STEAM connections with personal and professional transformation

Without delving too deeply into the vastness of theories of knowledge, it is important to pause and contemplate how *experience* envelopes the structural foundations of the STEAM learning process. Foundations in particular, related to the context of learning something new or in a new way. Cognitive science argues the human mind possesses the ability to override the application of ‘a priori’ knowledge in learning situations, not diminishing its importance, but rather adapting and converting beliefs to accommodate deep learning (Ohlsson, 2011). The basic knowledge forms conveyed in Kolb’s (1984) Experiential Learning Cycle, represented in Figure 2.3, provide a brief graphical summary of the contribution experiential learning has made, and continues to make, to the history of epistemological philosophy.

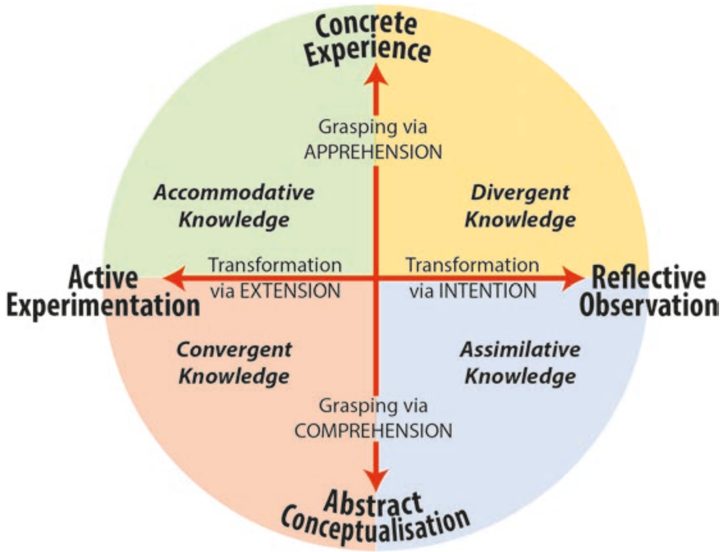


Figure 2.3: Structural Dimensions Underlying the Process of Experiential Learning and the Resulting Basic Knowledge Forms (Adapted from Kolb, 1984, p. 42)

Kolb's (1984) central idea is that learning and knowing "requires *both* a grasp or figurative representation of experience and some transformation of that representation" (p. 42).

Positive collegial relationships in education settings enhance healthy environments and individual teacher wellbeing (Liu et al., 2018). Liu et al.'s body of research is primarily related to how individual growth is linked to societal progress. And where societal progress places demands on educators, as in current STEM education agendas (see section 1.1), the symbiotic relationship of individual and collective wellbeing carries great weight in order for those educators to truly feel they are agents of social progress (Liu et al., 2018). Dewey's (1938) description defends genuine experience as influenced by the active degree in which "previous experiences have changed the objective conditions under which subsequent experiences take place" (p. 39). Alignment with such studies places STEAM learning in the realm of hybridised constructivist pedagogy within which connections made between experience and knowledge building are potentially transformative.

Transformative experiences have been described by Dewey (1938) in the literature as 'Erlebnis' – unmediated and in-the-moment experience, and Holdener, (2016) as 'immersion'. Erlebnis precedes judgement and inference. Kolb (1984) says "interest is the basic fact of mental life and the most elementary fact of valuing" (p. 104). Studies by Napier (2010) and Roberts (2012) value the learning in STEAM may be perceived as ‘aha moments’. Value judgements, as opposed to criticism, form the basis of appreciative behaviour (Kolb, 1984). Criticism, operationalised in the act of reflective observation, points us to the second of Dewey’s measures of experience: Erfahrung – reflective and cumulative experience. Both types of knowledge construction are potential contributors to the development and delivery of authentic transdisciplinary STEAM learning. Each is specifically inherent in the actions of critical thinking, championed by economic, education and entrepreneurial policy as vital to the skills needed for a new work order (Finkel, 2016; *National Innovation and Science Agenda*, 2015; Owen, 2015). Intersecting knowledge domains experienced through STEAM learning may provide the transformative experiences necessary for shifting teachers outside their comfort zone and into the realm of what Tait and Faulkner (Tait & Faulkner, 2016) consider *edupreneurship*.

2.3.3 STEAM curricular connections

This study relies on teacher engagement through personal and professional aesthetic experience, not unlike Berger’s (2003) quest to capture and share a culture of excellence, where learners care deeply about the quality of what they do. Few aesthetic, creative perspectives find their way into STEM learning (Henriksen & Mishra, 2020). “Conventional STEM education often misses the richness of disciplinary intersections”, and it would seem that educator reluctance or lack of professional motivation might add to the retention of traditional rigid structures of learning (Henriksen & Mishra, 2020, p. 2). Appreciation of the value of aesthetic output in STEAM aligns with Australian educational goals aiming to enable young people to understand the spiritual, moral and aesthetic dimensions of life; opening up new ways of thinking (ACARA, 2014c; MCEETYA, 2008). Teachers developing student experiences that result in products of learning being presented to external audiences, realise the importance of the audience response to the learning experience.

Audience feedback in relation to STEAM learning is meaningful. Such feedback may provide additional emotional input to both teacher and student self-efficacy. More objectively, making activities in practical and so-called aesthetic subjects, according to Gulliksen (2017) “are always in one way or another, giving us experiences that are multimodal and linked to our meaning making as individuals and as social and cultural beings” (Gulliksen, 2017, p. 10). Accolades are often meaningful to personal growth and "personal growth, meaningful work, being moved by beauty – all testify to the transformations that accrue in aesthetic experience" (Kerdeman, 2009, p. 90).

Terminology encountered throughout current NSW syllabi include "innovation", "authenticity" and "real-world learning". Key features of emerging curricula shift transferable knowledge and skills from subject domain specific projects to "designing, planning, managing and evaluating across the curriculum" (NESA, 2017, p. 10). Consistent with the Australian Curriculum's Cross Curriculum Priorities, ACARA's General Capabilities, defined by eight learning areas, can be viewed as conduits to transferable knowledge and skill (ACARA, 2014d). It is interesting to note that the relationship between priorities and capabilities is espoused as a way to allow for and encourage integrated and interconnected learning experiences that draw content across subjects. This may be a difficult enterprise for many subject specialist educators.

There are many common threads between STEM/STEAM curriculum development and contemporary innovative teaching and learning. The following pedagogical models present a brief overview of exemplar or similar curriculum frameworks, critically supported by robust professional development and establishment of collegial communities of practice (Hattie, 2017). Frameworks such as Project Based Learning (PBL), Visible Learning, Learning by Doing, and Design Thinking (Gettings, 2016; Hanney, 2018; Hunter, 2015). Combined, such methods of practice contribute to the way STEAM pedagogy aims to address current edu-political STEM engagement.

Project Based Learning (PBL)

A world class example of PBL exists in the much publicised pedagogical principles of High Tech High (HTH), in San Diego. HTH principles are: *Personalisation, Adult World Connection, Common Intellectual Mission, Teacher as Designer* ("High Tech High," 2016). The HTH model of education equality is culturally and ethically inspiring. HTH operates a non-selective admission, guaranteeing the readiness of all students for post-secondary education, work and citizenship. These principles are not dissimilar to the aims of all schools. However, what sets HTH apart is their commitment to interdisciplinary professional development from their inception in 2000. Project planning and tuning documents, openly shared with educators across the globe contain first-rate development, implementation and evaluation resources for Project Based Learning (PBL). Engagement in community-based learning and extending collaboration with adults “beyond the school walls” forms a major contributor to the breadth of learning experiences (p.1). The principle of *Teacher as Designer* nurtures professional development “in interdisciplinary teams to develop curricula and programs for 50 – 70 students per team” meeting for at least one hour daily for planning and staff development (p.1). HTH considers visible learning in the form of exhibitable student work as a key component of PBL.

Visible Learning

“The mantra of Visible Learning relates to teachers seeing learning through the eyes of students, and students seeing themselves as their own teachers” (Hattie, 2016, p. 10). Hattie is not making the case to say it is teachers who make the difference, but rather highlighting the variance provided by teacher effects where the measure of high effect teachers compared with low effect teachers can be evidenced by the advantages experienced by students. One major claim is that,

> the differences between high-effect and low-effect teachers are primarily related to the attitudes and expectations that teachers have when they decide on the key issues of teaching – that is, what to teach and at what level of difficulty, and their understandings of progress and of the effects of their teaching. (Hattie, 2012, p. 23)

Hattie goes on to say that teachers’ belief systems, including attributes such as being passionate and inspired, are closely related to what he terms ‘visible learning inside’ (p. 23). Further to teachers’ beliefs being of great importance, Hattie’s research in the area of *Visible Learning* delineated how little effect the teachers’ subject matter knowledge actually has on student outcomes. It was found that teachers’ beliefs about how to teach and understand predominated subject or pedagogical content knowledge. The differentiation is key to considering collaborative STEAM curriculum planning, as the experience of visible learning is dependent on how teachers organise and use content knowledge, often combined with *learning by doing*.

Connections between experience and learning are not singular. Ideas related to formative construction of knowledge through reflective and cumulative experience, Erfahrung, (Dewey, 1938), cannot be separated from the influence of emotional activity within Erlebnis, in-the-moment experience. Roberts (2012) balances Dewey’s pragmatic views on experiential education with Hattie’s (2012, 2016) promotion of appropriate challenge as a necessary principle for knowledge attainment. Hattie focuses on the

"Goldilocks principles of challenge for students (not too hard not too easy), while providing maximum opportunities for students to deliberately practice and attain these challenges" (Hattie, 2016, p. 10) and also promotes the same for pre and in-service teachers in that "the art of teaching is to help students enjoy the struggle" (p. 3). In STEAM learning, the struggle emerges within the transdisciplinary context where theoretical and practical elements of learning can be attained by physically *doing*. Making, or doing, transforms theory into practice in STEAM.

Design Thinking

Design Thinking is considered to be a transformative agent in education, being relatively recent but a necessarily active phenomenon (Prinsley & Johnston, 2015). Design Thinking emerged from the 'd.school', the commonly known abbreviated name for Hasso Plattner Institute of Design at Stanford (D.School, 2004). According to d.school, the result of undertaking a Design Thinking process guarantees people who use it to develop their own creative potential. Although Design Thinking can be applied in business and the public sector, in school education Design Thinking is used to create change, alter mindsets and arbitrate realities between problem solving in the classroom and in the real world. Empathy lies at the heart of Design Thinking. It is a process of creative and critical thinking that encourages acceptance and openness with a view to changing basic existing paradigms constructed from our attitudes and behaviours (McAuliffe, 2016; Ritchhart, 2015). 21st century pedagogies incorporate Design Thinking to increase the application of project based learning, computational and algorithmic thinking as well as embedding general digital literacy in learning (ACARA, 2014b; NESA, 2017). "What is critical to design thinking is the manner in which the designer solves the problem; divergent thinking" (McAuliffe, 2016, p. 4). McAuliffe argues there has been little informed understanding and exploration around divergent thinking that occurs during the design processes implemented in education, and how such thinking transforms into physical form. Design Thinking as a creative method or practice, may shifts paradigms. It attempts to create meaningful change in education (Hattie, 2012; Ritchhart, 2015). Applying Design Thinking to professional development in STEAM education affords opportunities for educators to develop strategies for collective understanding based on the needs and desires of the students, as well as concurrency with emerging innovative practice.

The literature acknowledges a myriad of existing innovative education models related to integrated learning, and to STEM/STEAM in particular. Transformative programs such as NSW Department of Education's iSTEM have attempted to implant interdisciplinary learning into current syllabus archetype structures, with direct focus on NSW syllabus outcomes. In operation, the integrated STEM projects achieved notable success within the education community. Appreciably, Design Thinking features within many of the integrated projects, as does project based and inquiry learning ("iSTEM," 2017). Education outliers operating in tandem with government-regulated innovation correspondingly align with transdisciplinary STEAM learning models.

Lumineer Academy

One such outlier is the "Lumineer Academy" in Victoria. Lumineer Academy is a member of a global guild of educationalists representing a new breed of disruptive teachers intent on pushing the limits of curriculum boundaries. Opened in February 2018, the 'startup' school is the brainchild of ex- Silicon Valley tech entrepreneur, Susan Wu, intent on creating an education revolution in Australia similar to entrepreneurial models: High Tech High and Elon Musk's 'Ad Astra' school. The mission of each of these schools is to develop lifelong learners who experience the world with joy, resilience and curiosity (Bailey, 2018; "Lumineer Academy," 2018). Abiding by national curriculum standards, students use goal setting to 'co-create' as much of their learning investigations as possible. Regarding STEM in particular, Lumineer Academy adopts the un-siloed holistic approach:

> We teach STEM as part of a foundational whole, that underpins all learning and making, rather than as silo'ed subjects. We teach STEM in synthesis with SEL (Social Emotional Learning) and Humanities. For example, when we teach robotics, we integrate the overall context of computational data, design, engineering, human rights, ethics, civics, and algorithm design. ("Lumineer Academy," 2018, p. 3)

Drawing on the Luminaria educational philosophy (see Figure 2.4), the academy promises to prepare students "to become the architects of — rather than mere participants in — a future world" (Baidawi, 2018, Para.4).

Figure 2.4: The Luminaria Educational Philosophy (Adapted from "Lumineer Academy," 2018)
SEL: Social Emotional Learning, STEM: Science Technology Engineering Mathematics

The attributes described in Luminaria Philosophy are pertinent and applicable to 360° teacher professional development as the current education environment navigates through innovative learning models disrupting the status quo. Even so, a question remains; where do the Arts fit in the Luminaria philosophy? Assuredly the A might be inserted to STEM, since over 70% of learning projects involve making.

2.4 In conclusion

Lifelong learners develop via enriching capacity for making and knowing, As Wu (2018), Dweck (2008) and Wagner (2012) have suggested. Capacity for making and knowing is strengthened by cognitive flexibility and resilience, as well as growth mindset, engaged empathy, ethical grounding and appreciation of passion, persistence, curiosity and wonder. Yet there is the question of evidence. Hattie (2016) has questioned the existence of evidence in scaling up innovation excellence in education. “The greater the challenge, the higher the probability that one seeks and needs feedback” (Hattie, 2016, p. 18). Hattie has made a blanket request for the “evidence of the evidence” (p. 18). Therefore, it is important to explore and align the micro discoveries among the common threads holding this research together. Observation of complex information being received and organised does not differ according to the age or experience of the teacher. Co-creation of transdisciplinary learning experiences might be operationalised using what Mason (2015) describes as “a form of learning on the *cerebral and cell layer*” (in Gulliksen, 2017, p. 10). Such learning allows the experience of emotions to enhance, detract, disrupt and transform a teacher’s view of themselves. Gulliksen (2017) says:

> Rich experiences give us a vocabulary — not only lingual, but with multiple forms of representations, with a variety of functional concepts — that is used when we learn how to represent and make ourselves through these languages (Gulliksen, 2017, p. 11)

Co-creating dense and focused STEAM activities in unfamiliar territory will be necessary to measure the richness of the teachers' experiences. Such rich STEAM learning experiences form the basis for this research and comprise the body of evidence analysed in the following chapters.

Chapter 3 – Research Methodology

> *Zeal for doing, lust for action, leaves many a person, especially in this hurried and impatient human environment in which we live, with experience of an almost incredible paucity, all on the surface. No one experience has a chance to complete itself because something else is entered upon so speedily. What is called experience becomes so dispersed and miscellaneous as hardly to deserve the name.* (Dewey, 1938, p. 46)

Literature reviewed in the last chapter, showed how "zeal for doing" and "lust for action" (Dewey, 1938, p. 38) in STEAM learning can be recognised in teachers by methodical chronicling of experiences collected through STEAM professional development (PL). The literature argued that teachers perceiving themselves as lifelong learners, enrich their capacity for transdisciplinary understandings related to making and knowing in STEAM. Such capacities are strengthened by cognitive flexibility and resilience, as well as growth mindset, engaged empathy, ethical grounding and appreciation of passion, persistence, curiosity and wonder. Transdisciplinary STEAM learning and its effect on teachers' identity was explored in the literature review, with a view to answering the questions underpinning this research:

- How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?
- How does experiencing activity emotions in STEAM projects enhance or detract from the teachers' personal identity development?

Chapter 2 presented literature related to transdisciplinary STEAM learning and the influence of teachers' emotions on that learning; human feelings that enhance, detract, disrupt and transform a teacher's view of themselves.

Before clarifying the methodology applied in this research, it is important reflect on the conceptual framework introduced in Chapter 1 (see Figure 1.2). I referred to hybridised constructivism as encompassing a phenomenographic approach to transdisciplinary learning experiences. Viewed through this dual theoretical framework, the need for decompartmentalising teachers' knowledge areas directed the study towards reinvigorated thinking about effecting pedagogy across disciplines. My aim, through the complex web of interpretation offered through the conceptual framework (Figure 1.2), was to encourage transformative teacher experiences through what Hanney (2018) proposes as doing, being and becoming. Such actions would be impossible to relate without socially situating teachers' learning in a particular context where teachers' interactions with each other *and* transdisciplinary STEAM content occurred in a moment in time, or over a period of time. Hence, the conceptual framework for this research emphasising constructivist hybridity and phenomenography.

In this chapter, the methodological context for data collection is presented within the framework of phenomenographic transformation. Simply put, the aim of the study was to document teacher transformations over time, in the place where the research was conducted. The pedagogical context of the research was STEAM teacher professional learning. Teacher participants in each case study represented those committed to action, similar to my own pedagogical commitment through the former teaching role as STEAM Coordinator at an inner-city independent school in Sydney, Australia. Phenomenographic transformation was dependent on developing a network of educators dedicated to exploring STEM to STEAM learning. My orientation to the research process was a direct result from membership of such professional learning networks, affording me opportunities to request teacher participation in STEAM research for the study. Over time, different strategies for STEAM implementation were developed in conjunction with the ethical requirements of the participant schools and my university.

All participants in this research were considered *learners,* with acute focus on teachers as learners, including pre-service and serving teachers, members of schools' executive and myself as teacher/researcher. Accordingly, data collected through mixed methods supported my philosophical positioning as participant researcher, giving cause to the approaches I have taken to investigate the STEAM learning context. I will begin this chapter by presenting the data collection timeline, then move to explaining the methodology that I used, arguing that the case study, combined with features of narrative and appreciative inquiries was the most suitable approach to provide answers to the research questions.

3.1 Field research timeline

STEAM projects and programs co-created for the study were unique to this research, and in STEAM cases 1, 2, and 3, were delivered to students in schools via a range of mechanisms. It is important to relate the timeline of the research, as each case was enacted within differing schedules, frequently overlapping. Figure 3.1 visualises the cases in a timeline demonstrating the development and delivery process. Consequently, time is employed as the instrument through which differentiation and feasibility of the cases are presented in Appendix D.

The feasibility of this research was reliant on appropriate size and scope of each case study. Consideration of appropriate selection of interviewee groups, their size and availability informed my approach. Data collection and analysis was supported by continual writing, evaluating the experience and outcomes of each formative activity undertaken as part of the research. Since the STEAM programs were considered sustainable by two of the participating schools, aspects of the research evolved into a semi-longitudinal study. Hence, data was collected over two years in STEAM 1 and 3, and one year in STEAM 2 and 4. The benefits of a semi-longitudinal inclusion allowed for the pedagogy and practice in STEAM teaching to evolve, providing greater scope for comparative analysis.

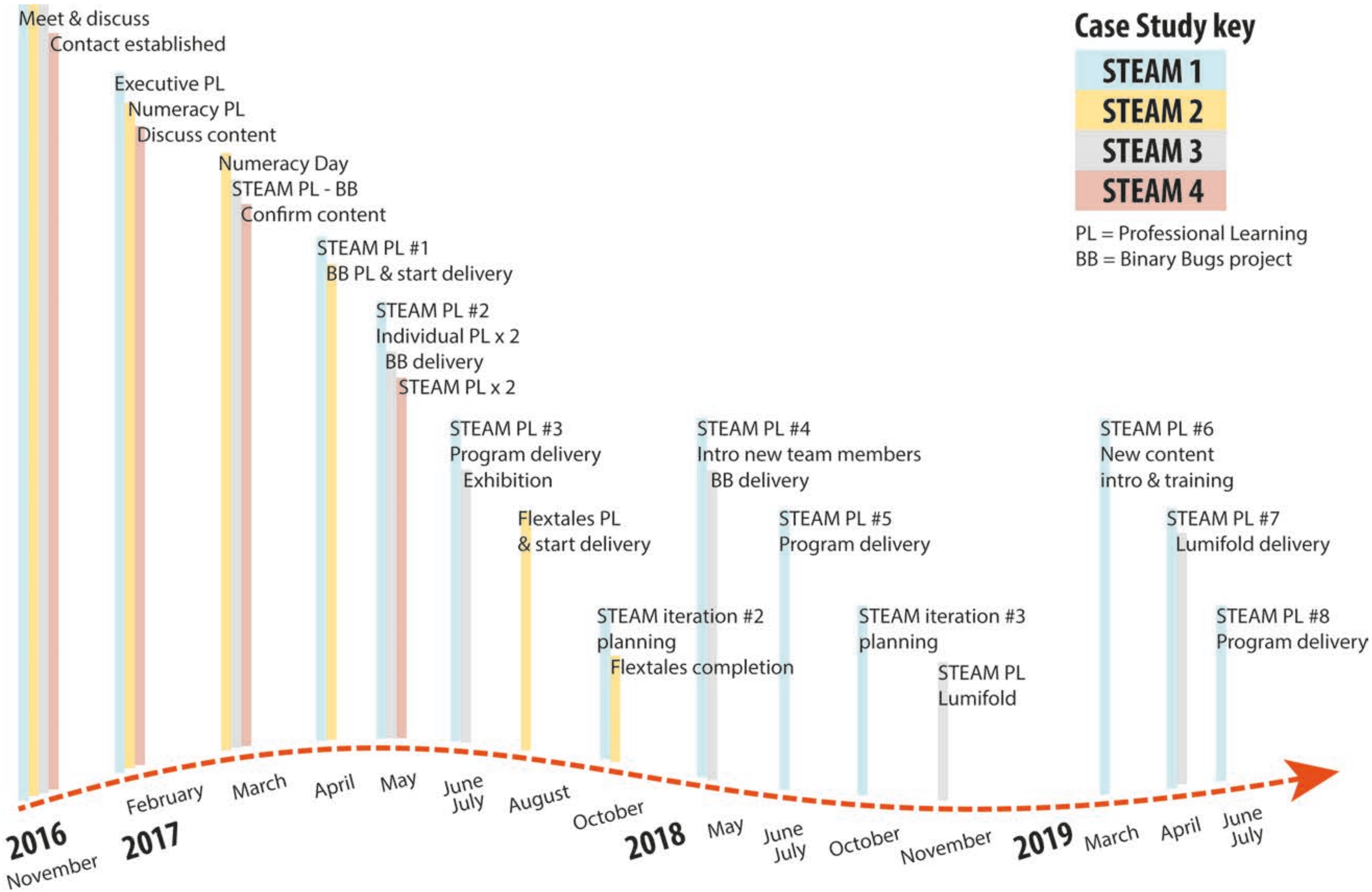


Figure 3.1: Timeline illustrating STEAM case studies development and enactment.

The complexity of the study required me to operate as participant researcher in the cases of STEAM 1 and STEAM 2. These, and STEAM cases 3 and 4 warranted varying degrees of teacher PL, delivered by the researcher (myself), or with additional support from executive STEAM team members. While self-immersion in teacher PL reinforced my aim to answer the qualitatively driven research questions, potential contamination of the collected data was to be avoided. By this I mean my presence during delivery stages of the STEAM projects to students needed to be objective and not interventional. While operating in the role of PL facilitator, it was difficult to not 'step in and help' because this is the role of any person delivering professional learning to industry peers. The strategies applied to teacher training and instructing were applied in the context of 'ownership'. That is the teachers were required to 'own' their learning in order to deliver new knowledge and skills to their students. Interpreting the data could be seen as problematised in the sense that "observer effects" (Monahan & Fisher, 2010, p. 357) might result in biased analysis. However, the phenomenographic framework supporting this research augmented the range of observations I was able to make, by virtue of establishing familiarity with the research participants (particularly in STEAM 1 and 2). Marton (1988) maps phenomenography as fuller perception and understanding of situations, aspects and events, and I was careful to include data that was displeasing to me as much as data which confirmed the transformative features of the participants' STEAM experiences. Monahan and Fisher (2010) argue that "informants' performances – however staged for or influenced by the observer – often reveal profound truths about social and/or cultural phenomena"(p. 358). Critical reflection with active disengagement from emotion even in the face of negative results found such truths to be apparent in this research.

3.2 Research questions

The research questions being investigated were targeted towards teachers' understanding of transdisciplinary learning, and the role emotions play on the development of teacher personal and professional identity during learning in STEAM. When the fruit of one's effort is visible, as in many concept-to-completion STEAM programs, growth mindset behaviours supersede the more general 'boosting self-esteem' approach of indiscriminately praising everyone and everything. Acknowledging that all of us are a mixture of fixed and growth mindsets (Dweck, 2008) permits us to feel the emotion and challenge of being outside one's comfort zone. Such challenge guided the direction of this study, steering towards the first research question:

> **How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?**

The question relates to transformative learning experiences. Particular emphasis is placed on teachers' understanding of connected pedagogy through engagement with specific mathematics and/or science concepts, blended with the arts. The study aimed to provide exposure to circumstances within which many intersections of such concepts were relatable and meaningful in the lives of the teachers as learners. Such provision manifestly linked to the second research question underpinning the study:

> **How does experiencing activity emotions in STEAM projects enhance or detract from the teachers' personal identity development?**

Within the bounds of this research, changes to a learner's personal identity was acknowledged as being freshly situated understanding of STEM through an Arts experience (either by immersion or a series of activities). Activity emotions can be variously described, ranging from the experience of joy and delight to anger and frustration. Formal observation recorded in analytic memos after PL sessions provided supportive qualitative data to semi-structured interviews related to how the teachers responded to the STEAM activities undertaken in each case setting. As well as leading much of the PL, my research interest was in observing teacher behaviour; namely comments, actions and gestures related to stepping outside one's personal and pedagogical comfort zone. Keeping both research questions in mind assisted my observation of teacher behaviour across the cases. What emerged was steeped in rational and empirical approaches to the narrative and appreciative inquiry methodologies applied in the study. Formal and informal interview data as well as group reflections were collected within a conscious framework of sub-questions in mind (see Figure 3.2).

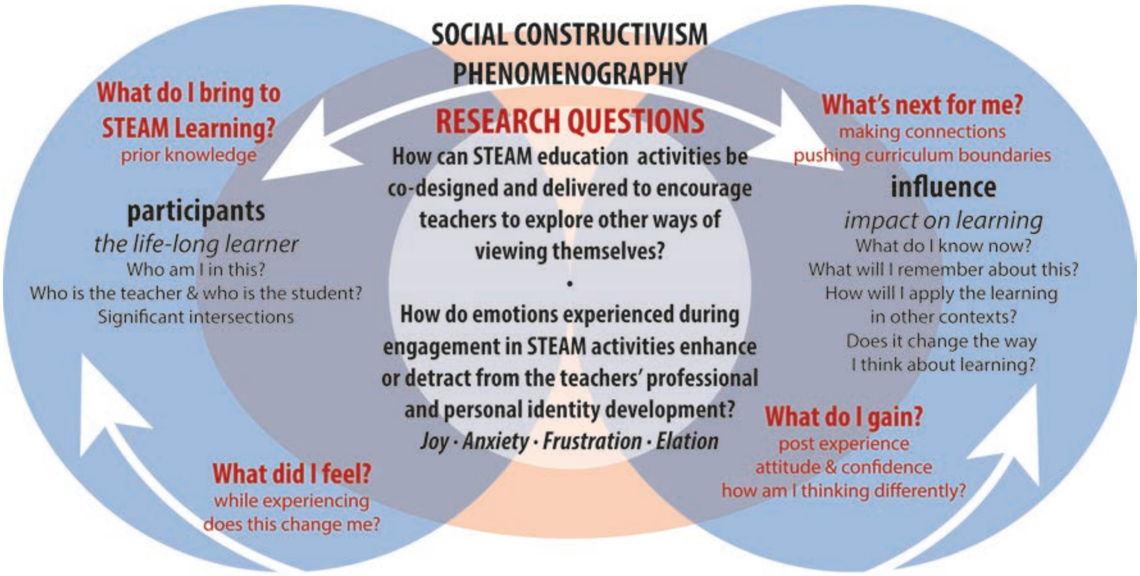


Figure 3.2: Thesis questions embedded in context within the Conceptual Framework for this study
(See Figure 3.2)

The sub-questions represent reflective individual inquiry, questions intrinsically relevant to mixed methods data collection within the theoretical framework of social constructivism and phenomenography:

- What do I bring to STEAM learning? *Prior knowledge*.
- What did I feel while immersed in the STEAM experience? *Aesthetic experience*.
- What do I gain from the STEAM learning experience? *Personal transformation, new knowledge, self-confidence.*
- What's next for me? *Continued connected pedagogy, pushing curriculum boundaries*.

Integrating the sub-questions in teacher interviews for the study enabled more nuanced and contextualised participant contribution. Given that the symbiotic relationship between teacher and student learning frequently relied on the development of individual and collective efficacy, the data collection was targeted towards exploring the shifts in teacher self-efficacy and identity. My intention was to ascertain how such two-way flow of learning in STEAM might lead to sustainability of the STEAM projects. Needless to say, within the study, gathering data for analysis with a view to finding evidence of shifts in identity was as complex as the STEAM projects themselves.

3.3 Case Study justification

The Case Study methodology was chosen for this research due to its appropriate provision of comparative analysis opportunities. Each case presented a similar system of STEAM learning for teachers. However, the complexity of integrating the cases demonstrated that teacher participants were not obliged to achieve one goal and one only. Collection of semi-longitudinal qualitative data in STEAM 1 and 3 resulted in a more extensive analysis of affect, in the human psychological sense, and effect, from the perspective of developing pedagogy. Revisiting the programs in those cases, over two years of delivery, assisted in establishing whether activity emotions recorded at the time of the first delivery changed or influenced other learning situations or expectations. While STEAM 2 and 4 cases did not involve iterative delivery to students, all cases provided a structure and framework to observe, interview, document, reflect on and interpret data, through subjective and objective contextualised qualitative measures. Understandably, features of narrative and appreciative inquiry traditions were incorporated into the overarching case study methodology.

The emergence of story and narrative is well documented by education researchers, most of whom consistently refer to Dewey's (1938) consideration of the quality of interaction and continuity within the study of experience (Huber, Caine, Huber, & Steeves, 2013). "Education is life and life is education, and to study life, to study education, is to study experience" (p. 220). A principal element of narrative inquiry highlights the broadened scope of the relationship between the researcher and the researched. Drawing on narrative inquiry permitted me to present a relational understanding between myself as researcher and the actions and interests of the participating teachers – their journey, their stories. Narrative inquiry related directly to how I might answer the research questions underpinning the study. Being participant researcher in each case setting afforded my recording of key characteristics of the teachers' experience, defined in terms of personal, social, temporal, and situational. Such characteristics were also bound by three of the case contexts being situated in schools.

Similarly, the generative nature of appreciative inquiry, according to Cooperrider, Zandee, Godwin, Avital, and Boland (2013) affords investigation of a person's capacity for rejuvenation and innovation, often inspiring people to create something unique. Therefore, features of appreciative inquiry crept into the case study methodology due to the fact that I was looking for, and documenting, teacher transformation through unique STEAM learning experiences. Drawing on the appreciative inquiry approach permitted the ordinary magic noted by Cooperrider et al.,

(2013) of teachers' learning to be recorded in each case study and analysed as a contributory method of understanding how transdisciplinary dialogues can come into existence. Blending teachers' stories (narrative), with the joyful mystery in discovery (appreciative), brought flexibility, malleability, and adjustability of my research design to the comprehensive comparative analysis of the case study methodology. Appreciative inquiry, melded with the narrative, challenged the manner in which the data was analysed, in that boundaries between researcher and researched were often blurred, resulting in generative nuanced analyses of teacher transformation during the STEAM learning experiences. Avital and Te'Eni (2009) argue that "generative design can help ordinary people to achieve extraordinary results" (p. 364). This is what I was researching across the STEAM cases. Thus, my capacity as researcher was to challenge the teachers' status quo while simultaneously participating in collecting stories that aimed to revitalise our collective epistemic stance related to STEAM transdisciplinarity.

As mentioned earlier in this sub-section, teacher participants in the STEAM programs and projects were not required to achieve one goal and one only. Teachers' STEAM learning was an integrated system, undeniably cross-curricular but specific to individual circumstance in each case setting. In defence of the use of case studies in my research I refer to Stake's (1978) proposition that the *case* itself, is an integrated system.

> The parts do not have to be working well, the purposes may be irrational, but it is a system. Thus people and programs clearly are prospective cases. Events and processes fit the definition less well. (Bassey, 1999, p. 27)

Figure 3.3 displays the complexity of the four case studies, and Figure 3.1 indicates concurrent times in which they were enacted. Tables 3.1 to 3.4 show how each case explored four different ways of developing and delivering STEAM understanding to a range of teachers, in order to facilitate the same STEAM learning to students. STEAM 1 incorporated six sessions of PL, ranging from three hour to whole day events. STEAM 1 PL supported the development and delivery of a STEAM immersion using a project-based learning model over seven consecutive school days in the first year and eight in the second year. STEAM 2 required four planning and skill PL sessions to develop competency in embedding the STEAM learning into curriculum over three terms. STEAM 3 was provided with a half day PL in support of a ten-week transdisciplinary STEAM program delivery. Additional 'top-up' PL was provided in the second year of delivery. STEAM 4 nominated two sessions of teacher PL including different attendees for each two-hour session (see Table 3.4). Participants in STEAM 4 aimed to incorporate their learning in appropriate contexts within their own schools. Detailed chronologies and description of each case is located in Appendix D. It is important to note that while some of the STEAM projects enacted across the cases were similar, the method of enactment was not the same, but was co-designed with participating teachers considering the needs of their students and schools in mind.

3.4 Research Design

An overview of the research complexity is illustrated in Figure 3.3 and following tables. Seven STEAM projects were developed for inclusion, each unique to this study. The research data collection was located across four case study locations including three school settings and one professional association gathering held over consecutive weeks at two school locations. Corresponding to the literature review, case studies informed the research appropriately. Case studies use multiple sources of data collection methods. The case study research approach afforded the collection of individual stories to build a broad cohesive narrative, and was the best approach for researcher immersion in such individually nuanced edu-ethnographic settings. Qualitative data was collected through situations within which large *and* small experiences could be measured. Qualitative inquiry, activated through the case study method, provided a foundation for data collection strategies including semi-structured interviews, group evaluations, artefact analysis, documented photos and videography, plus audio recording. Collecting audience feedback, recording participatory observation (analytic memos), and reflective journaling were also influential data collection methods. Whilst mixed methods adopted in this study resulted in collection of data not exclusively qualitative, the increasing relevance of qualitative methods such as participatory observation and post-project interviews were acknowledged as crucial during the research progression.

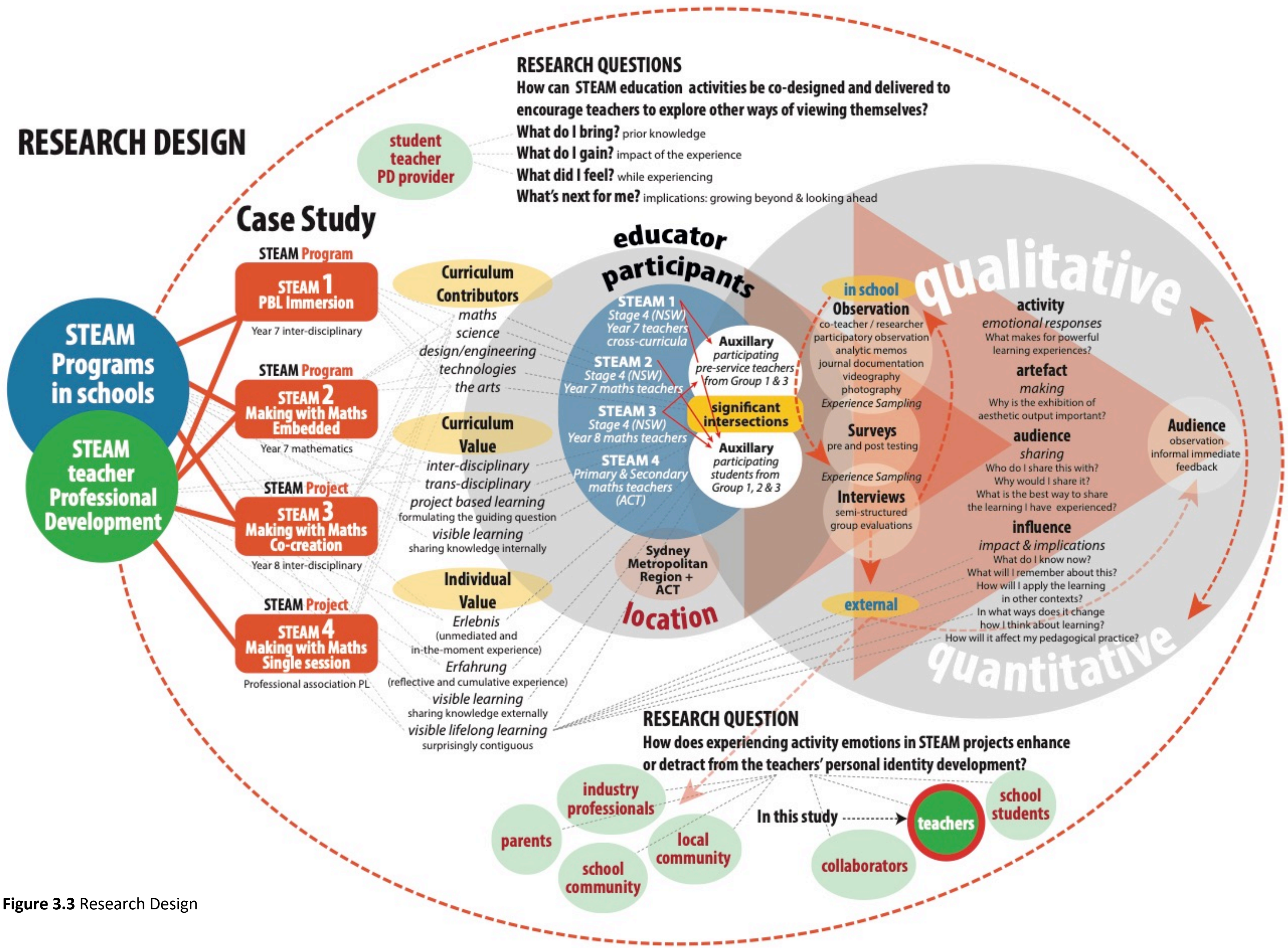


Figure 3.3 Research Design

It is important to note that terminology in Figure 3.3 describes STEAM 1 and STEAM 2 as STEAM ‘programs’, while STEAM 3 and STEAM 4 are considered STEAM ‘projects’. The differentiation is due to the method of STEAM learning included in each case study, ranked according to the number of teacher PL sessions. Participants in the study were drawn from a number of key learning areas. Apart from Mathematics, subject disciplines such as English, History, Personal Development, Health and Physical Education (PDHPE), Science, Visual Arts, Music, and Technology were represented, each contributing explicit and nuanced phenomenographic processes and language specific to that discipline. Tables 3.1 through 3.4 provide an overview of the research design from each case in terms of its location, which STEAM projects were enacted, the number of teacher and student participants, and data collection timeline. Data was collected during teacher meetings and PL, as well as during the STEAM programs’ delivery to students.

Table 3.1: Research Overview: STEAM 1 Case Study.

<table>
<tr><td>STEAM 1 CASE STUDY
LOCATION: SCHOOL 1</td><td>Demographic Description
School/Organisation</td><td colspan="3">Comprehensive coeducational secondary school in south-western Sydney. Student population is culturally and linguistically diverse with more than 90% of students from a language background other than English, predominantly Vietnamese, Cantonese and Assyrian.</td></tr>
<tr><td>STEAM PROJECTS</td><td colspan="4">Binary Bugs • Lumifold • Future Movers • Flextales • This is Me • This is Us</td></tr>
<tr><td colspan="3">TEACHER PROFESSIONAL LEARNING - STEAM CONCEPTS</td><td>PARTICIPANTS</td><td>RESEARCH DATA COLLECTION TIMELINE</td></tr>
<tr><td colspan="3">STEM ←——→ ARTS</td><td colspan="2">YEAR 1</td></tr>
<tr><td colspan="2" rowspan="3">• Innovation
• Powers
• Binary systems
• Probability (randomness)
• Elementary symmetries
• Translations on the plane
• Geometry
Incl.'hidden' geometries
• Tessellation
• Biomimicry
• Engineering
Structure
Strength
Stability</td><td rowspan="3">• Patterning
• Tessellation
• Biomimetic design
• Paper engineering
• Architecture
• Textile design
• Colour theory
• Design Elements and principles
• Making
• Metaphor
• Representation
• Materials technology</td><td>8 teachers
14 pre-service teachers
122 students</td><td>6 PL days with teachers
7 days STEAM immersion with Year 7 students
3 evaluation sessions with teachers
1 evaluation session with executive</td></tr>
<tr><td colspan="2">YEAR 2</td></tr>
<tr><td>5 continuing teachers
3 new teachers
2 pre-service teachers
124 students</td><td>2 PL days with teachers
8 days STEAM immersion with Year 7 students
1 evaluation sessions with teachers
1 evaluation session with executive</td></tr>
<tr><td colspan="5">TEACHER PROFESSIONAL LEARNING - STEAM SKILLS</td></tr>
<tr><td colspan="5">• Empathy skills
• Collaboration
• Creativity & critical thinking
• Problem articulation & Problem solving
• Design thinking
• Cross-platform navigation
• Digital image manipulation
• Exhibition presentation skills
• Storytelling – narrative creation (individual, community, culture)</td></tr>
</table>

Table 3.2: Research Overview: STEAM 2 Case Study.

STEAM 2 CASE STUDY LOCATION: SCHOOL 2	**Demographic Description School/Organisation**	Comprehensive girls' secondary school situated in south-western Sydney. Student population is approximately 536 girls from diverse cultural, religious and socio–economic backgrounds, with 98% of the girls from a language background other than English, predominantly Middle Eastern, South–East Asian, Pacific Islander and African.
STEAM PROJECTS	**Binary Bugs • Flextales • Hyperbolic Paraboloids**	

TEACHER PROFESSIONAL LEARNING - STEAM CONCEPTS		**PARTICIPANTS**	**RESEARCH DATA COLLECTION TIMELINE**
STEM ⟷ ARTS		**YEAR 1**	
• Innovation • Powers • Binary systems • Probability *(randomness)* • Elementary symmetries • Translations on the plane • Geometry *Incl.'hidden' geometries* • Ratios • Conic sections • Tessellation • Biomimicry • Engineering	• Patterning • Paper engineering • Architecture • Textile design • Colour theory • Design Elements and principles • Making • Literacy - narrative creation • Metaphor • Representation • Working properties and characteristics of materials • Visual Aesthetics	6 teachers 84 students	4 sessions PL with teachers *(approx.. 2hrs each session)* 1 lesson per fortnight with Year 7 students over 3 terms 1 evaluation session with teachers 2 evaluation sessions with executive

TEACHER PROFESSIONAL LEARNING - STEAM SKILLS			
• Empathy • Collaboration	• Creativity & critical thinking • Problem articulation	• Problem solving • Algorithmic thinking	• Digital image manipulation • Storytelling – narrative creation

Table 3.3: Research Overview: STEAM 3 Case Study.

<table>
<tr><td>STEAM 3 CASE STUDY
LOCATION: SCHOOL 3</td><td colspan="2">Demographic Description
School/Organisation</td><td colspan="3">Large comprehensive inner western Sydney school for girls. Student population is culturally diverse with approximately 75% from a language background other than English, including International students.</td></tr>
<tr><td>STEAM PROJECTS</td><td colspan="5">Binary Bugs</td></tr>
<tr><td colspan="4">TEACHER PROFESSIONAL LEARNING - STEAM CONCEPTS</td><td>PARTICIPANTS</td><td>RESEARCH DATA COLLECTION TIMELINE</td></tr>
<tr><td colspan="4">STEM ←——→ ARTS</td><td colspan="2">YEAR 1</td></tr>
<tr><td colspan="2" rowspan="3">• Innovation
• Powers
• Binary systems
• Probability (randomness)
• Elementary symmetries
• Translations on the plane
• Geometry
• Tessellation
• Biomimicry
• Engineering
Structure
Strength
Stability</td><td colspan="2" rowspan="3">• Patterning
• Tessellation
• Biomimetic design
• Paper engineering
• Architecture
• Textile design
• Colour theory
• Design Elements and principles
• Making
• Metaphor
• Representation
• Materials technology</td><td>11 teachers
1 pre-service teacher
178 students</td><td>1 PL session with teachers (half day)
1/2 lessons per week with Year 8 students over 10 week period
1 evaluation session with teachers</td></tr>
<tr><td colspan="2">YEAR 2</td></tr>
<tr><td>11 continuing teachers
175 students</td><td>1 PL top-up session with teachers
1/2 lessons per week with Year 8 students over 10 week period</td></tr>
<tr><td colspan="6">TEACHER PROFESSIONAL LEARNING - STEAM SKILLS</td></tr>
<tr><td colspan="6">• Empathy
• Collaboration
• Creativity & critical thinking
• Problem articulation
• Problem solving
• Algorithmic thinking
• Design thinking
• Exhibition presentation skills</td></tr>
</table>

Table 3.4: Research Overview: STEAM 4 Case Study.

<table>
<tr><td colspan="2">STEAM 4 CASE STUDY
LOCATION: Professional organisation – members meeting</td><td>Demographic Description School/Organisation</td><td colspan="3">Volunteer run mathematical association and affiliate of the Australian Association of Mathematics Teachers (AAMT), representing professional educators of mathematics from one Australian state or territory. Primary and Secondary mathematics teacher members.</td></tr>
<tr><td>STEAM PROJECTS</td><td colspan="5">Binary Bugs</td></tr>
<tr><td colspan="4">TEACHER PROFESSIONAL LEARNING - STEAM CONCEPTS</td><td>PARTICIPANTS</td><td>RESEARCH DATA COLLECTION TIMELINE</td></tr>
<tr><td colspan="4">STEM ⟷ ARTS</td><td colspan="2">YEAR 1</td></tr>
<tr><td colspan="2">• Innovation
• Powers
• Binary systems
• Probability (randomness)
• Elementary symmetries
• Translations on the plane
• Geometry
• Tessellation
• Biomimicry
• Engineering
Structure
Strength
Stability</td><td colspan="2">• Patterning
• Tessellation
• Biomimetic design
• Paper engineering
• Architecture
• Textile design
• Colour theory
• Design Elements and principles
• Making
• Metaphor
• Representation
• Materials technology</td><td>27 teachers</td><td>2 sessions PL with teachers
(approx. 2.5 hrs each session)</td></tr>
<tr><td colspan="6">TEACHER PROFESSIONAL LEARNING - STEAM SKILLS</td></tr>
<tr><td>• Empathy
• Collaboration</td><td colspan="2">• Creativity & critical thinking
• Problem solving</td><td colspan="3">• Algorithmic thinking
• Design thinking</td></tr>
</table>

3.4.1 Recruitment

The participating schools were approached through identification of interest within a range of teacher professional networks. Final selection was due to leading teachers and executive at each location expressing a desire to increase innovation in learning and teaching practice, focussing on STEM and STEAM. These were the educators who were willing to play. Hence, the parallel objective of the research was an intention to professionally develop participating teachers in a range of unique STEAM activities that might ensure sustainability of the integrated learning content, beyond the scope of the study. Bilaterally, STEAM sustainability was also the aim of the participating teachers.

3.4.2 Ethical consideration

Adherence to the University's Responsible Conduct of Research and the National Statement on Ethical Conduct in Human Research was mandatory and ethical approval from UTS Human Research Ethics Committee (HREC) was obtained (see Appendix A). Formal recruitment in line with UTS Human Ethics requirements recognised the initial expressions of interest from principals, head teachers and representatives from professional learning associations by their receiving information on the project and an invitation to participate. Following receipt of positive responses, the on-flow of information and consent documents related to conducting research in schools required by both UTS Human Ethics and the NSW Department of Education (DoE) State Education Research Applications Process (SERAP) (see Appendix B) was efficiently developed and distributed (see Appendix C). More detailed explanation of ethics applied in the study is included in the individual data collection methods described later in this chapter.

3.4.3 Participants

Graphic representation of the number of participants is illustrated in Figure 3.4. While the four STEAM programs underpinning the study differ in delivery and context, each of the school co-created programs maintain similarity of some, but not all, content. Figure 3.5 codifies and labels the case study contexts as STEAM 1, STEAM 2, STEAM 3, and STEAM 4. Each case occurred at different schools and locations. Tables 3.1 to 3.4 outline the vision, demographic and cultural range of the participants from each learning environment. STEAM 1, 2 and 3 are contextualised in NSW Government schools (public) while STEAM 4 is situated in a professional association context. The range of data collected for analysis sits within the timeline of STEAM PL and delivery to students in STEAM 1, 2, and 3, and teacher PL in STEAM 4. Hence the total number of teacher participants is 58. However, this number proved to be unwieldy in terms of collecting more nuanced and intimate data associated with professional and personal identity development during STEAM learning. Intensive qualitative data was sought from a core group of participants within the collective 58. The core group was chosen because of their commitment to the STEAM programs over a period of time and availability of access for pre and post interviews. More specifically, interviews with participants from STEAM 1 and STEAM 2 form the body of analysis in greater depth. My involvement with those programs in particular, as researcher, PL facilitator, and STEAM project co-creator, provided rich opportunities for full immersion in all aspects of STEAM evolution at those locations. Tracking professional and personal transformation occurring as a result of inclusion in the STEAM programs was dependent on building rapport and strong pedagogical understandings between myself as researcher, and those participating in the research.

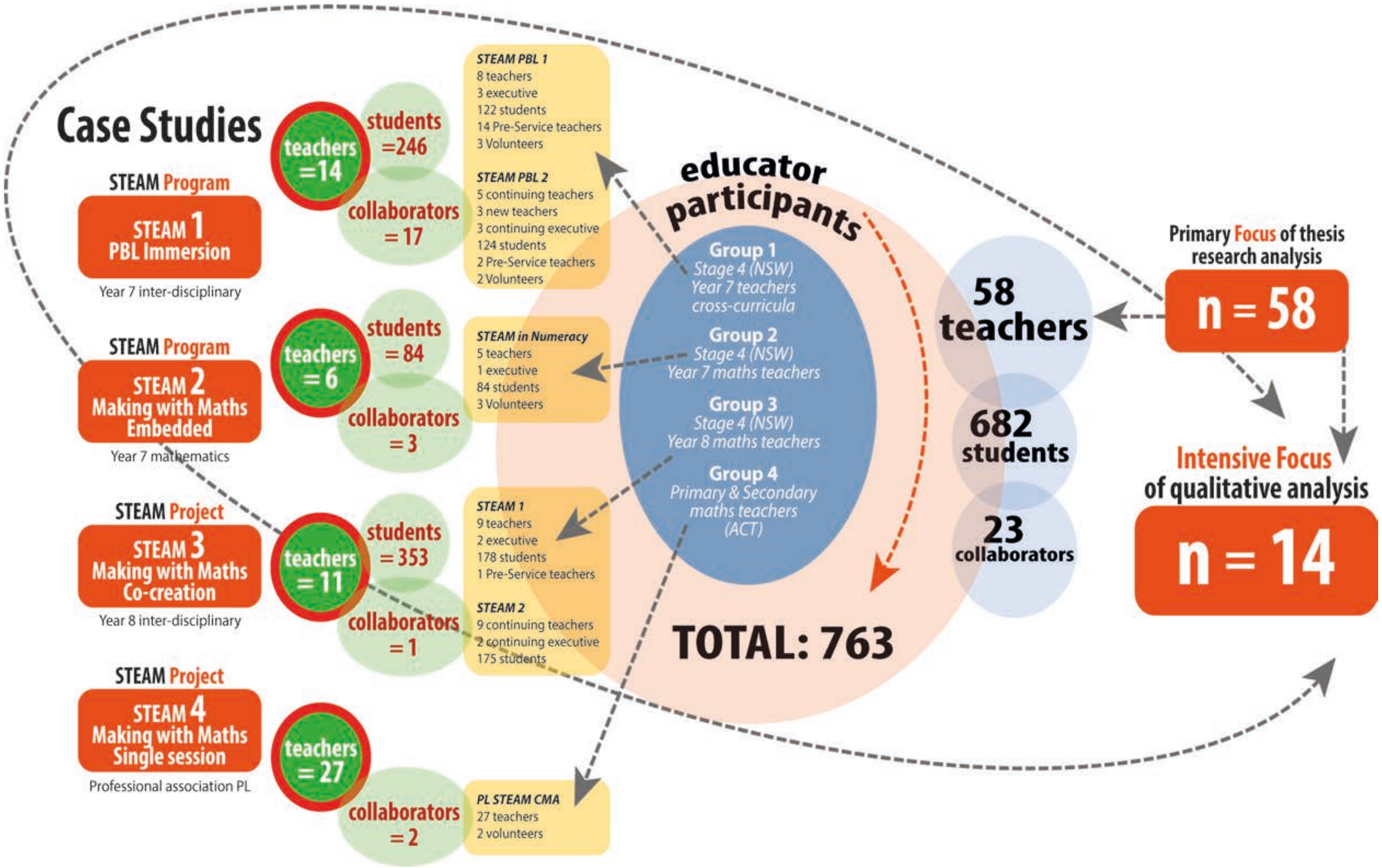


Figure 3.4: Case study participant numbers

3.4.4 Anticipated problems

The main obstacle to collecting and analysing data for this study was not finding participants; it was managing the scope and number of participants within the range of STEAM projects developed in collaboration with the participating schools. Figure 3.5, extracted from the overall case study research design (see Figure 3.3) illustrates how participation selection was pared down, identifying the variety of STEAM learning models utilised in the final PL and/or delivery to students. Innovative approaches to developing content that aimed to balance contributions from all STEAM learning areas was a new approach in each case. Teacher participants generally had little or no idea of what their STEAM project might look like due to the freshness and originality of each case study design. Tables 3.1 to 3.4 provided a brief overview of the range of STEAM content utilised within the cases, demonstrating the variety of technological innovation built into the STEAM learning. Consequently, teacher PL undertaken as part of the research resulted in considerably more process-driven instructional activities than expected. A vast range of resources was produced, particularly in the area of technology use, for ongoing professional development and sustainability of the STEAM programs in three cases; namely, STEAM 1, 2 and 3.

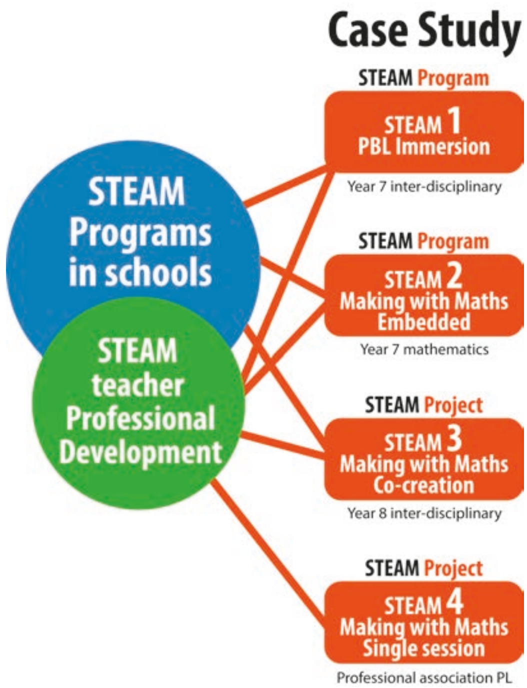


Figure 3.5: Case study focus drawn from Conceptual Framework (See Figure 1.2 in Chapter 1)

The range of instructional resources produced to support the teachers' learning was co-designed in a way to provide the same task for teachers as the students would be required to undertake. Teachers were to identify where the pain points in learning would occur. The term 'pain points' is used in design thinking strategies in which empathy exercises enable the understanding of human interactions with specific experiences. STEAM 1, 2 and 3 involved much instructional testing in order for teachers to empathise with situations in which students might experience difficulty in the STEAM learning activities. Instructional resources were tested in collaboration with all participating teachers in STEAM 1, 2, and 3. Testing proved an invaluable experience for improving the way tasks were delivered from one STEAM program to the next. Constant iteration provided much evidence of projected teacher ownership of individual projects within the greater STEAM programs. Co-design and iteration contributed to the validity of incorporating appreciative inquiry features to the case study methodology. Samples of process guidance and instructional resources applied in this research can be viewed in Appendices B and C.

3.5 Research Methods

Considering the co-design undertaken in the development of STEAM learning underpinning the research, the most effective data collection method was observation.

Encouraging teachers to explore other ways of viewing themselves through engagement with STEAM also required many informal interviews during PL sessions. The same was necessary during STEAM program delivery, reinforced by participatory observation and analysis of reflections recorded in the field, immediately after the event. A small measure of pre and post survey data was also collected with a view to supporting qualitative data associated with teacher's shifting views of pedagogical capacity. In terms of experiencing activity emotions during STEAM learning and the effect of such instances on teachers' sense of personal identity, more nuanced observation was recorded and supported using Experience Sampling (ESM) at key moments during the PL. Formal interviews conducted post-delivery provided rich data informing the second research question more suitably, due to the emotional responses to completion of the challenging STEAM projects. Formal interviews, conducted privately, revealed distinct insights related to individual personal development, including less positive outcomes from the experience. More broadly, participatory observation, field notes, ESM, group reflections and aspects of the teacher surveys, aimed to provide certainty to the positive or negative outcomes revealed in the research analysis. Mixed and interweaving methods allowed for comparative analyses of the effects of STEAM program participation across all cases. Conversely, formal interviews with teacher participants also exposed fissures in their STEAM experiences. However, it was the provision of such individual, personal and humble reflections that made vital contributions to the legitimacy of the research in its narrative entirety.

3.5.1 Observation

Observation throughout the STEAM PL sessions and delivery to students was key to obtaining comprehensive understanding of how all participants in the STEAM programs responded to the learning. This research method forced me to appreciate the behavioural similarities and differences between the people I observed, including myself. Aspers and Corte (2019) in attempting to define 'qualitative' consider observation as an iterative action, taking place over a duration. The authors consider the method of participatory observation allows the researcher to get closer to the phenomenon being studied. In my research, two types of observation were employed: participatory and peripheral. Each served a different purpose. The first gave me access to observe collective teacher and student learning in the context of STEAM form and content. The second allowed me to experience first-hand, the small, seemingly trivial cumulative changes occurring in the professional and personal identity of the participating teachers. Spending much time in faculty planning meetings and PL afforded me opportunities to look more attentively, scrutinise both discourse and body language, and notice the often-unremarkable things that identified emotional responses to STEAM learning. My assumption was that silence, for example, was symptomatic of palpable growing anxiety related to the complexities of the projects. Moments of intense joy were also unmistakably present when learning or making breakthroughs occurred. Such activity emotions are analysed in greater detail in the next chapter. Recording my observations took place either in-the-moment or immediately after individual PL sessions or meeting with participating teachers. Generally, these were notes entered on a laptop or audio recorded using the voice memo function of a smart-phone. These recordings and entries were collated into chronological field notes ready for coding.

3.5.2 Field notes, photography, video and audio

Regarding ethical considerations, teacher participants were aware of my frequent field-note taking, sometimes offering me additional insights unsolicited. Systematic digital journaling was necessary to record what happened in the lead up to delivery of each STEAM program, also during delivery, and post participation. Analytic memos were used in the form of self-recorded voice, written diarised entries recorded physically or digitally (depending on circumstances), and a variety of documentation by photography or digital audio and/or video. It is said that many recorded scenes come to life in the analysis (Katz, 2015). Therefore it is important to note that writing up the research observations, permitted previously considered assumptions to present contradictory results. Katz (2015) states that "recorded field notes provide no insurance against the nonrecording of inconvenient facts" (p. 123). Field notes, supported by photography, video and audio aimed to record teachers' experiences without bias, resulting in several instances of perceived negative responses to STEAM learning, which through analysis presented contradictory outcomes. These are explained in detail in the next chapter.

In accordance with ethical permissions granted by HREC and SERAP, the identities of teacher participants were not recorded in photography. If necessary, de-identification was undertaken at a later date using image manipulation software. Frequently, teacher participants offered their own contribution to photographic evidence, uploaded in shared online drives such as Google drive, Google classroom, Teams and DropBox. Video artefacts were required as content for some of the STEAM projects and not strictly used in the analysis of teachers' experience in the research. However, video data presenting the student artefacts surprisingly elicited emotional responses from the teachers. Such responses were recorded by observation and included in the overall data analysis. On occasion, video data served as a reminder of the complexity of the STEAM projects in case studies 1 and 2. Photographic data provided evidence of teachers' learning activities during PL, supporting the analysis of the outcome of their STEAM experience in combination with other methods. Photographic data alone were not indicative of teacher transformation, therefore were only coded according to the documentation of individual STEAM projects. These projects are outlined in next chapter and explained in detail in Appendix E.

3.5.3 Interviews

The process of collecting interview data depended on building a certain rapport with the teacher interviewees. As a method crucial to qualitative methodologies, teacher interviews enabled me (the researcher) to capture rich experiences from teachers' STEAM learning in ways that Lemon & Budge, (2016) describe as subtle and nuanced. Such particulars informed and guided the individual teacher stories into a meaningful collective narrative. Permission to be interviewed was provided by all teacher participants via informed consent as part of the HREC and SERAP ethics approval. As the study evolved, semi-structured interviews with pre-service and in-service teachers participating in the programs became more familiar and openly expressive. Questioning was fluid, guided by participant responses. Opportunistic informal interview material was also recorded in regular analytic memos with annotations as to identification, context and value. Not surprisingly, interviewees offered many tangential comments, leading to rich and deep comprehension of the perceived value or lack of value of the STEAM programs.

Interviews took place in a variety of environments such as staff rooms, cafes, excursions, exhibitions and walking to and from classrooms. Similarly, there was temporal variation in data collection resulting in interviews taking place in both pre and post program delivery, in person, by phone in the evening when children were in bed, during term and non-term times and within the context of conference calls. Negotiation of interview times was predictably difficult, given the constraints of teacher timetables, their designated break times and on a personal level, family commitments. Ethical consideration warranted teacher/researcher negotiation, particularly when an interview was scheduled outside school hours. A preferred time and place, therefore, was negotiated with the interviewee, always on their terms.

3.5.4 Group reflections

A variety of empirical methods are applied in qualitative research, each contributing to a naturalistic approach to data collection (Aspers & Corte, 2019; Silverman, 2007). In this research, there were many opportunities to gather reflective comments from participating teachers in relation to their level of personal and pedagogical comfort in delivering STEAM activities to students. While many teachers enthusiastically participated in collaborations to understand the relevance of STEAM to their teaching practice, there were also a number who actively avoided the challenge. Group reflections recorded during STEAM delivery to students phases was an appropriate method to apply given the complexities of STEAM activities in STEAM 1 and 2. Recording discord at the same time as documenting positive outcomes of the STEAM learning aimed to provide accuracy in documenting the integrity and authenticity of participating teacher experiences. The STEAM projects required hand-made and digital activities requiring teachers to establish a degree of hierarchical comprehension necessary for integration into the proposed cumulative STEAM outcome. Group reflections supported the authenticity of phenomenographic transformation being measured across all cases. By this, I mean the provision of teachers' 'in-the-moment' reflections in support of formal interviews conducted after the STEAM projects were completed. Aspects of teachers' responses to STEAM learning during group reflections were also indicative of Csíkszentmihályí's (1990) notion of flow, where neural activity potentially led to moments of total absorption. Such moments were also recorded using an Experience Sampling Method.

3.5.5 Experience Sampling

Experience Sampling (ESM) provided a means for collecting information in the immediacy of the moment. Such moments were related to learning new STEAM content in unfamiliar contexts, theoretical, physical and digital, within each of the case study settings. ESM provided respite points in the professional learning schedules, underpinned by basic reflection questions such as: “How are you feeling?”. Live data collection tools recorded the teacher responses dynamically. Aggregated feedback was immediately available to teacher participants in STEAM 1 PL, providing peer validation ‘in-the-moment’ via online data visualisation. Using ESM in conjunction with live data collection in PL, enabled teacher respondents in the group to see the frequency of their emotional responses in the actual moment the emotions were felt, without time for considered reflection. ESM was used three times throughout BB PL from 44 respondents across three STEAM cases. Experience sampling preserved the immediacy of the moment, allowing fewer opportunities for participating teachers to reflect after the event. Lack of time was a factor affecting ESM data collection, hence the provision of an adjective list from which teachers chose their responses was considered appropriate. The quantitative method analysed the frequency of responses, and was conducted before, during and after BB in STEAM 1, 3, and 4. The list of adjectives changed according to the ESM question. Analysis of the data collected through PL related to BB was shared with participating teachers in order to encourage empathetic understanding of what the students might experience when undertaking the same BB activity. Figure 3.6 depicts a sample representation of chosen adjectives, based on frequency, activated in one session of STEAM PL in STEAM 1 (n=14). The word cloud displays ‘experience’ terminology based on the frequency of teacher response to the question: “how are you feeling about the STEAM PBL immersion right now?”. This particular sample displays data collected during the first PL session at School 1, after teachers had been introduced to the STEAM program proposal and content coverage. The size of the words denotes the frequency of a specific emotion being identified.

Figure 3.6: Sample live data collection using ESM. N = 14.

Figure 3.7 shows an alternative live data visualisation method. This sample was collected during the second session of STEAM 1 intensive PL. ESM was used to gather teacher responses (n=14) to the question "What is your biggest concern right now?". ESM is typically used as an intensive longitudinal method allowing "researchers to study the relationships within and between everyday behaviours, activities, and perceptions" (Bolger & Laurenceau, 2013, p. 12). When assessing the impact of emotional experiences during the study, ESM was acutely beneficial because the method allows for ascertaining whether STEAM experiences were influential at the time of delivery.

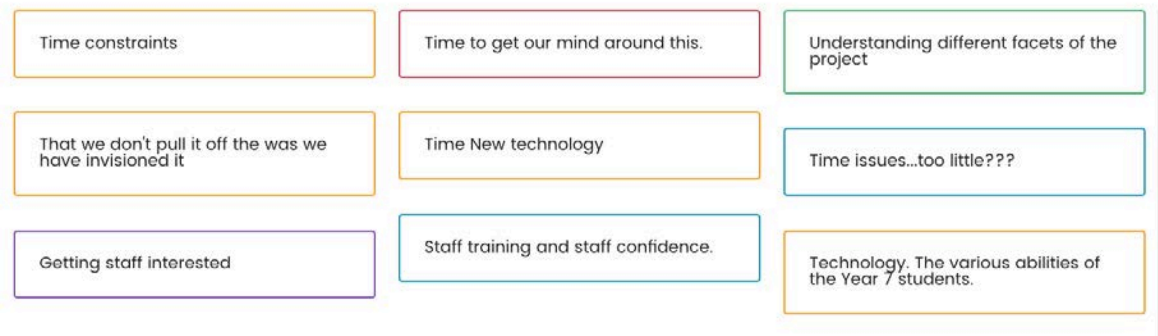


Figure 3.7: Live data collection using ESM method. N = 14.

ESM was a comfortable fit in my research design as the method requires no retrospection or response burden, but relies on sampling of "real-time thoughts, feelings and behaviours in context" (Bolger & Laurenceau, 2013, p. 17). In this way, the quantitative data collected through ESM proved an essential analysis element supporting qualitative data collected using varied instruments.

3.6 Analysing the qualitative data

Aspers and Corte (2019) determine qualitative research as often naturalistic. The experiences recorded within the four STEAM case studies undertaken in this research were also largely naturalistic. Analysis and interpretation of such experiences afforded claims that were indicative rather than generalised. Further research incorporating larger data sets would be needed to make generalisable claims. What was achievable and justifiable in this research, however, was the opportunity to record a variety of stories from as many teacher participants as possible, within a range of STEAM learning contexts. Hence the case study methodology being situated in the phenomenographic framework as phenomenongraphy qualitatively maps "ways in which people experience, conceptualise, perceive, and understand various aspects of, and phenomena in, the world around them" (Marton, 1986, p. 31). The analysis of collected teacher stories required systematic data transcription and coding in order to locate themes in the narratives that addressed the research questions. The empirical materials used in the case study methodology applied in this research meant that the mixed methods approach did not provide standardisation. Consequently. indicative claims in the research analysis, fell into the realm of 'fuzzy logic' (Bassey, 1999, p. 27), meaning that sketchiness was valued over accuracy. However, the research claims *are* indicative of individual teacher transformation, essentially derived from measuring shifting collective and individual experiences, even if the experiences are gleaned from a small group.

3.6.1 Analysing spoken discourse

All structured and informal interviews, group reflections, and audio field notes were transcribed either manually or using an online transcription service. There were over thirty audio recordings contributing to qualitative data collected for this research. Where possible, tone of voice was captured in bracketed descriptions prior to, or following, individual teacher comments. Rapport established between myself as researcher and the teacher participants assisted the ease with which interviewees responded to my questions. Inevitably, much of the discourse communicated personal opinion and judgement, strengthened with vehement views on the current educational climate. It was necessary to apply specificity and filter such discourse to extract the most relevant comments related to the research. Since the study focused primarily on the transformative effect of STEAM in teacher PL, discourse predictably delved into intrinsically human qualities. Those qualities have been interleaved in all interviews, with a view to addressing the research questions and presenting the value of the study to education communities.

Data from spoken word was coded into a table divided into themed headings: Transdisciplinarity, Activity Emotions, and Sustainability. Each theme was then analysed in detail according to sub-themes related to the literature and more specifically with Wagner's (2012) innovation attributes of play, curiosity, fearlessness, passion and purpose. Figure 3.8 illustrates how the themes generated three focus areas informing the data analysis structure applied in the next chapter.

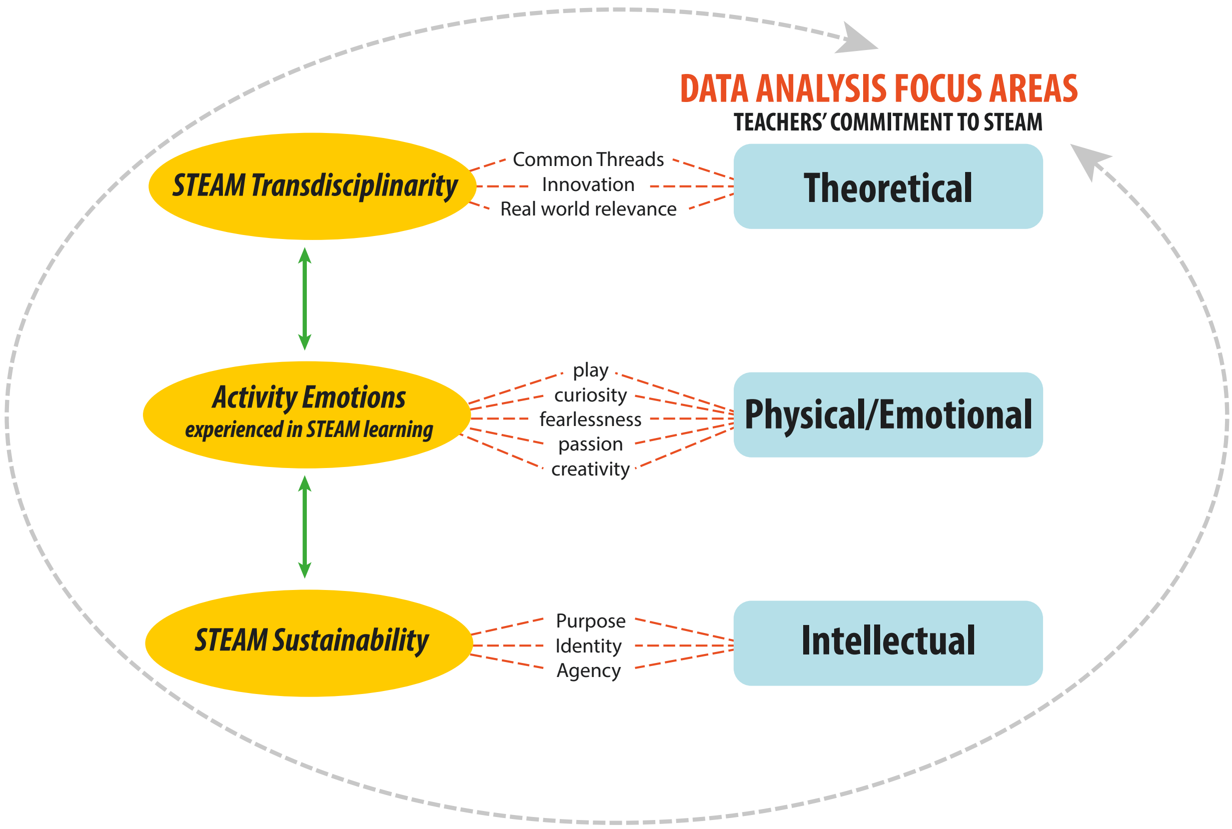


Figure 3.8: Data coding structure.

3.6.2 *Documenting data analysis*

Stated earlier in this chapter, much of the video recorded during STEAM 1 and 2 was for the school's own documentation of the STEAM programs. Photographic documentation provided a method for chronologising the data in terms of teachers' progress through STEAM PL sessions and subsequent delivery to students. The purpose of image documentation was to support the understanding of the visual complexity of the STEAM projects co-created for this research. Very occasionally, video or photographic evidence served to support the subtle and nuanced aspects of teachers' experiences recorded in interviews and group evaluations. More specifically, images reference the positive components of the teachers' experience. For example, there is much photographic evidence of joy and elation as a result of maths-making and participating in external exhibitions. While such evidence supported the presence of activity emotions, visual examples did not portray the more troublesome activity emotions such as frustration and anger. Therefore, this method of data collection was not coded and analysed with the same rigour as interview and group evaluation comments.

Field notes were included in the coding structure outlined in Figure 3.8. Cross referencing field notes across the cases was crucial to generating themes that led to the establishment of the three focus areas investigating teachers' commitment to STEAM from the theoretical, physical/emotional, and intellectual perspective. These are analysed in detail in Chapter 4. Cross referencing field notes continually focused my attention to hunches and challenged my presuppositions about teachers' engagement with STEAM learning. Katz (2015) warns against finding patterns in field notes when the researcher gives weight to interactions from one view alone. The logical value of field notes in this research was that they provided chronologies from a phenomenographic perspective, attempting to locate similarities and differences in teachers' behaviour before, during, and after STEAM learning sessions.

3.6.3 Including quantitative data

While the case studies relied on qualitative research predominantly, pre and post testing was also built into STEAM 1, and 2. Developed as a Likert-type scale, a series of closed questions related to STEM awareness and the relationship between STEM and the Arts, were posed to participant teachers before PL and after the program completion at each location It is important to note that pre and post testing was enacted in Year 1 of the research timeline. The questions targeted perceptions related to STEM awareness and how/where STEM subject content intersected with the Arts environment, and, key to the research questions, how the intersections influenced the teacher/learners' lives. The survey also identified teachers' emotions experienced during engagement in STEAM activities contributing to the STEAM PL experience.

3.6.4 Limitations to data collection and analysis

Regarding informal interviews recorded during the delivery of STEAM 1 and STEAM 2 programs, it was important to adopt strategies that utilised collective time in the best possible way in terms of productivity. Principally, the strategies of training, instructing, resourcing, and then stepping back to encourage teacher ownership of the learning was grounded in the need for efficiency. Self-nominating as part of the delivery team, meant that appropriate distance needed to be established in some instances, in order for participant teachers to own the learning and potentially experience shifts in self-perception, without influence from the researcher (myself). Researcher influence could be perceived as a limitation when in real terms and in real time, all participants wanted the projects to be successful. Analyses of such tricky situations formed both individual and collective narratives. Providing analysis of individual instances in the research without combining their input to the greater whole would be a mistake. Consideration of particulars within the boundaries of each case study was worthwhile and contributory to the structure of the research overall. However, Stake (1978) argues “to know particulars fleetingly of course is to know next to nothing” (p. 6) and combining them might lead to not so relevant indicative claims. Therefore, it was necessary to analyse the permutations of fuzzy and naturalistic generalisation within this study due to the gathered evidence being located in a range of personal, individual and collective experiences.

On the ground, limitations were more obvious. A major obstacle to the smooth operation of each STEAM program was the range of interdisciplinary skill levels presented by participating teachers. Certainly, each teacher was considered expert in his or her subject, yet may not have experience connecting the level of expertise with another subject area. Since STEAM includes the use of technology, limitations existed in proficient technology skill in many PL instances. Consequently, the scope of professional development increased by large degrees before the programs could be implemented with students. PL was supported by strategic planning of staff learning sessions, coordinated by the leaders of each STEAM program, then reinforced by the creation of a large range of digital and physical resources (see Figures 3.7 to 3.10). Where programs required interrelated digital tasks, other members of the school community were engaged, particularly the technology teachers and ICT support staff.

Limitations in the form of teacher resistance was evident in the behaviours of some participants. Each case posed its own positive and negative characteristics, which provided legitimacy and authenticity to the research analysis. During field work and data collection phases of the research, a vast amount of data was collected. Such vastness became a significant limitation. Yet collecting data associated with relationships between educators and educated in STEAM 1, 2 and 3 programs necessarily contributed to the analysis of the experience. Relational inputs such as these are included in findings detailed in the following chapter.

3.6.5 Research rigor

While case study is the key methodology underpinning this research, it is still imperative to note the way teacher narratives fed into both phenomenon and method (Huber et al., 2013). Investigating teachers' capacity for revitalising pedagogy through STEAM innovation carried narrative and appreciative inquiry value in each case. In reference to de Bruin's (2017) 'microworld' of learning, in which learning is validated by placement in context, documenting the range of peer-to-peer experiences over the course of the STEAM programs increased the trustworthiness of the study. Up-skilling the participant teachers on site, was extremely conducive to cultivating de Bruin's so-called microworld, an activity system of learning "in an authentic work setting, where learning is more likely to be clearly contextually situated" (de Bruin, 2018, p. 87). The study aimed to bridge a gap between STEAM education research and practice for the participating teachers. While it is fair to say that this type of transdisciplinary learning is not 'one size fits all', qualitative methods aimed to investigate the many unknowns in teacher participant perceptions.

3.7 Chapter conclusion

The purpose of this chapter was to set out the methodological context for data collection within four STEAM case studies, in which teacher transformation was temporally documented. Seven individual STEAM projects were enacted in the four cases over a time frame of two hours to two years. Examination of teacher behaviours throughout that time warranted the consideration of nuanced personal and professional interactions to be recorded via mixed methods. Qualitative data was supported by incidental quantitative results (ESM), rendering phenomenographic teacher transformations as crucial to understanding the challenges and complexities inherent in developing transdisciplinary STEAM learning. Each case study context was suitable for STEAM teacher *and* student learning, marking teachers' self-perception in ways that impacted the sustainability of the STEAM programs in the locations where they were enacted.

The following chapter includes a brief description of the seven STEAM projects enacted throughout the research, based on the chronology represented in the research data collection timeline in Figure 3.1. STEAM project descriptions are necessary to support the findings, as themes and focus areas emerging in the data aim to provide answers to the research questions. Detailed descriptions and case study chronologies are located in Appendix D and E. In Chapter Five, the findings are discussed in relation to empirical themes explored within the Literature Review, with a view to acknowledging how teacher transformations of any size are contributory to the ongoing development of STEAM learning 'microworlds'. Such microworlds position STEAM learning as authentic, contextual and important to evolving teacher professional and personal relevance in transdisciplinary education future-making, thereby securing a valid contribution to the education research field.

Chapter 4 – Findings From the Data.

Because peers are living and working in similar conditions, with similar students, peers help to clarify and affirm ideas in context. (Beauchamp et al., 2014, p. 34)

Literature reviewed in Chapter 2 presented three affective contexts facing teachers participating in STEAM learning: transdisciplinarity, activity emotions, and pedagogical and curriculum connections. What emerged from the literature were interconnected themes drawn from future-making research related to STEAM teacher transformation, focusing on the effects of innovative practice on teachers' adult identity and professional agency, creativity, emotions and personal experience. The previous chapter presented the research methodology, case studies timeline (Fig. 3.1), and rationale for the mixed methods approach, including the process and methods used in data collection and analysis. Participating teachers were situated in four case studies including three school settings and one professional association location (Fig. 3.3). Seven STEAM projects were developed for inclusion, each unique to this study (Tables 3.1 – 3.4). Interpersonal data collection methods ranged from semi-structured interviews to experience sampling (ESM), allowing for qualitative and quantitative teacher responses to be collected both in-the-moment and through group evaluation and/or individual reflection. Participatory observation and analytic memos provided additional data for analysis of the foci related to the questions underpinning this research.

This chapter firstly presents the findings' thematic structure, identifying three focus areas for analysis, before introducing the key to differentiating data from the case studies. Following the key, seven STEAM projects are described, and serve as clarification reference points for the subsequent data analysis. Findings from the data are structured according to the affective contexts drawn from relevant literature. Emergent themes aligned with views held by Beauchamp et al. (2014), in that teachers engaging in STEAM professional learning (PL) on site, with a view to implementing the same learning to students, were able to contextualise transdisciplinary STEAM ideas, and serve as learning partners for each other "on a more regular, embedded basis" (p. 34). 'On-site' refers to STEAM professional learning (PL) at the site of the participating school. It is important to note where data collection occurred external to a school setting (in the case of STEAM 4), identical methods were applied as those in the case studies conducted in school environments.

The overarching theme emerging from the data was the expression of teacher transformation through STEAM learning experiences. Small and large transformations formed the foundation for interrogating findings related to both research questions: *How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?*, and: *How do emotions experienced during engagement in STEAM activities enhance or detract from the teachers' professional and personal identity development?*

Embedding myself as participant researcher in each case setting, afforded the privilege of familiarity in relation to peer rapport and collegiality established between participant teachers. Data collection was shaped by frequent research instances in which teachers' display of individual and collective passion, fearlessness and purpose, was present. Further instances provided evidence of the rich benefits of play and curiosity in teacher PL. Such attributes are identified by Wagner (2012) as necessary for creating innovative learners. Each attribute combined to address activity emotion affect during teachers' transdisciplinary learning. While data collected for this study was "both planned and serendipitous" (Meyer & Turner, 2002, p. 107), the findings responded to the research questions using a robust foundation of the case study methodology, supported by features of narrative and appreciative inquiry traditions (Cooperrider et al. (2013); Huber et al. (2013). The narrative is after all a story, a key thematic feature of the social sciences academy. Appreciative inquiry considered deeper levels of potential in teachers' stories, focusing on the human state of productive persistence and the development of tenacity and strategic skills for the delivery of successful STEAM programs to students. Figure 4.1 illustrates the thematic structure underpinning the research findings. The structure is designed according to teacher experiences in three STEAM learning focus areas: theoretical commitment, physical/emotional commitment, and intellectual commitment. It is through these foci that teacher transformation was measured.

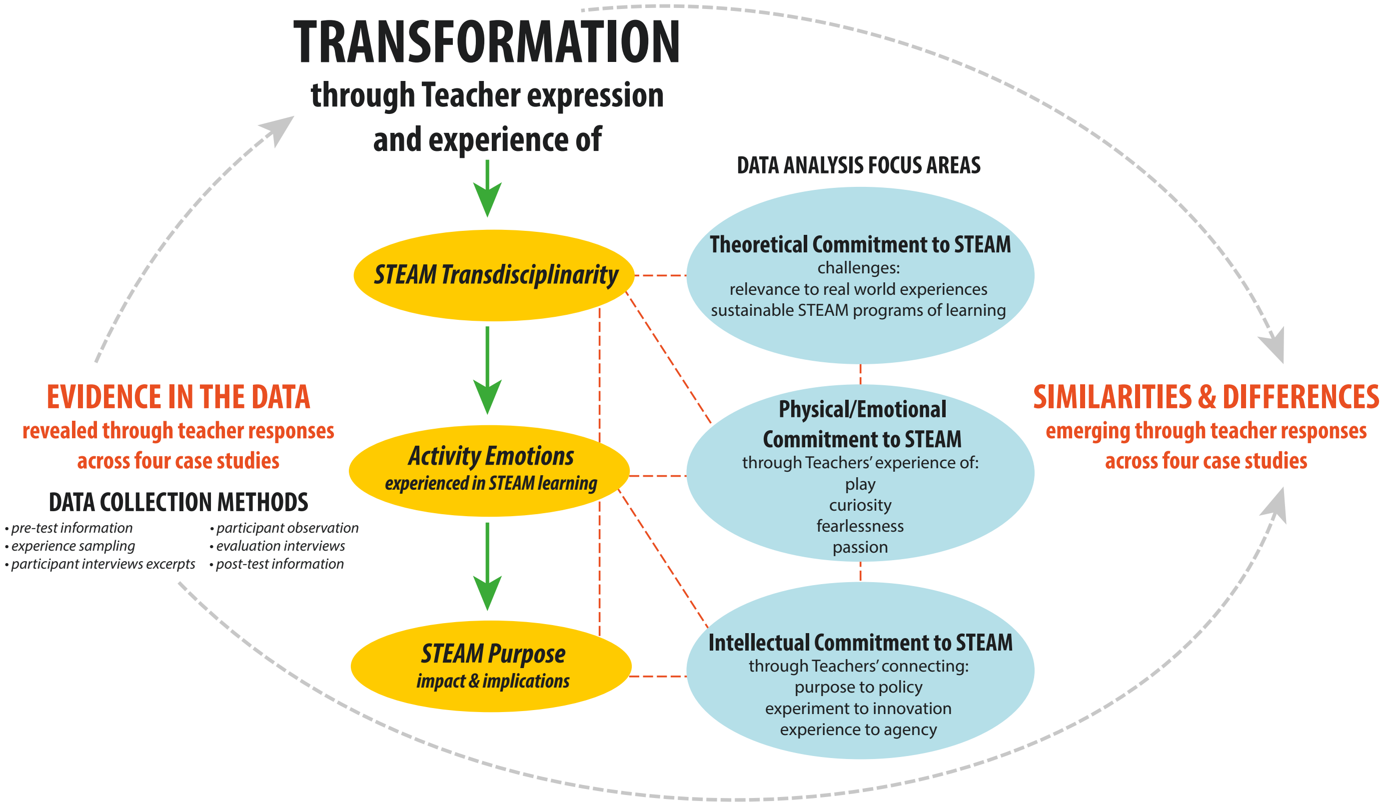


Figure 4.1: Thematic structure of findings.

Tracking changes to teachers' individual and collective identity warranted application of mixed methods data collection via researcher participation. The mixed methods approach afforded my coverage of key changes in relationships between the researcher and 'the researched' (Huber et al., 2013). Collecting and analysing a range of research data from different styles of STEAM content creation and delivery, provided indication of how teachers developed and practiced their craft in innovative STEAM learning settings, and how the learning experience contributed to personal and professional growth. Therefore in this chapter, a thematic narrative showing teacher transformation underlies much of the findings, reinforced by evidence of teachers' willingness to play, be fearless, curious and passionate about what they were trying to do. Figure 4.2 indicates the structure of emergent sub-themes necessary for anchoring the teacher narratives within the three identified focus areas.

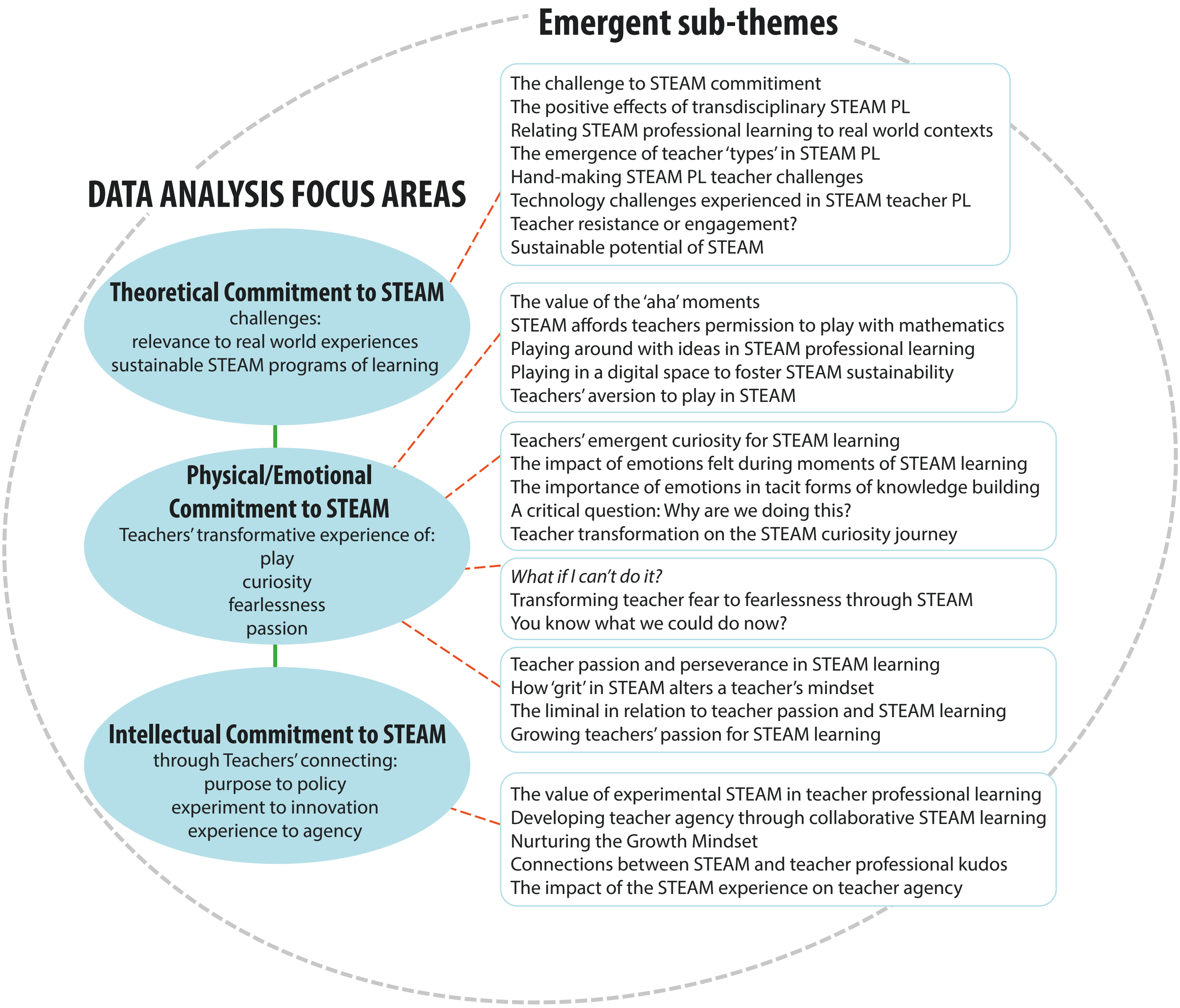


Figure 4.2: Sub-themes analysed in the findings.

4.1 Three focus areas:

theoretical, physical/emotional, and intellectual commitment to STEAM

Each focus area addresses above aspects of the research questions, through findings relating to the emergent sub-themes. The foci present evidence of teacher motivation to engage with transdisciplinary STEAM, teacher willingness to get hands-on and minds-on in STEAM education settings, and how teacher professional and personal aptitude are enhanced through connected conceptual knowledge construction. Sub-themes emerging from the data provided opportunity for more detailed analysis in order to position the research in a framework of what I have termed *hybrid constructivism* (see

3.1), that is, learning experiences deeply grounded in a socio-constructivist, phenomenographic approach.

Theoretical commitment refers to how teachers respond to and engage with transdisciplinary education challenges related to integrating Arts concepts with STEM content. Focus area two relates to evidence of teachers' *physical/emotional commitment* to STEAM learning. Visceral, in that such commitment communicates how the participating teachers played, and expressed curiosity, passion and fearlessness for STEAM learning. The third focus area, *intellectual commitment* presents the experimental and experiential nature of STEAM PL. Teachers' intellectual commitment is presented through data relating to how STEAM pedagogy serves curriculum, yet simultaneously establishes links between teacher identity and agency. Each of the focus areas aim to correlate transformative teacher experiences recorded in STEAM learning, with a view to measuring the value of such transformation in terms of its impact on and implications to the lives of the participant teachers.

4.2 Case Study key

Four case studies operationalised for the research were described in Chapter 3, (see Tables 3.1 to 3.4). Findings from each case were cross-analysed and mapped according to the contribution of teachers' personal and professional stories. Colour coded icons are positioned throughout the body of this chapter. Figure 4.3 indicates the colour linked to the case study provenance: Case Study 1 = STEAM 1, Case Study 2 = STEAM 2 and so on.

Figure 4.3: Colour coding the case studies.

Individual research participants have been colour coded according to their location within a specific Case Study. For example: 1T1 = STEAM 1 – teacher 1. Table 4.1 provides a key to the hierarchical position of teacher participants included in the study.

Table 4.1: Key to differentiation of case study participants

1P	STEAM 1 Principal
1DP	STEAM 1 Deputy Principal
1T1	STEAM 1 PBL Coordinator
1T2 – 1T9	STEAM 1 Teachers
1PST	STEAM 1 Pre-service Teachers
1T1 – 1T5	STEAM 2 Teachers
1T1 – 1T8	STEAM 3 Teachers
3PST	STEAM 3 Pre-service Teacher
1T1 – 1T7	STEAM 4 Teachers

Tables 3.1 – 3.4 in the previous chapter identify which individual STEAM projects were enacted in each case study. It is important to note that in STEAM 1, all components of the seven STEAM projects were undertaken through three annual iterations of the Year 7 STEAM program delivery to students. Two of such iterations are included in the data collected for this study. All cases were analysed concurrently due to the STEAM programs or projects being conducted at the same time. Figure 3.1 shows the research timeline in terms of data collection, justifying the comparative analyses traversing across the case studies. Such cross analysis supported the thematic structure of the research analysis outlined in Figure 4.1 earlier in this chapter. The timeline in Figure 3.1 provides an overview of when each of the seven STEAM projects co-created for the study were enacted across the four case studies. The following section of this chapter briefly describes each STEAM project and how the learning concepts built from one

another. As the research was located in Australia, the execution of STEAM ideas in teacher PL was necessarily situated in a local context. Therefore, teacher PL was aligned with Australian and/or New South Wales curricula drawn from Mathematics, Science, Technologies and the Arts - Visual and Media Arts in particular. Detailed explanation of each project can be found in Appendix E.

4.3 STEAM Project Descriptions

4.3.1 Project 1 – Lumifold

Lumifold (LF) is a mathematical paper folding activity, initially developed during my final years of high school teaching, and amended for this study. The LF activity requires the folding of pre-scored paper templates to form three-dimensional shapes which are illuminated by light emitting diodes (LEDs). The foundation for LF derived from a collection of definitive guidelines curated by Paul Jackson, an origamist specialising in 'Sheet to Form' workshops for designers of all disciplines, as well as mathematicians, scientists, educators, and others (Jackson, 2011). In this study, I call the making experience 'flat to form', and created specific templates for use in teacher PL and STEAM project delivery to students. The LF design is unique to my research practice, and please note that the 'glide reflection' construction method is applied in both Lumifold and Binary Bug projects.

Lumifold provided opportunities for the recognition and discussion of numerous mathematical and STEAM concepts during teacher PL in STEAM 1. *Making* involved folding paper templates of varying sizes and manipulating the folds into hills or valleys (up or down) according to origami *sekkei* rules and conventions. Origami sekkei is a Japanese phrase meaning 'computational' or 'mathematical' folding. There are two specific auxetic patterns inherent in the LF outcome: a rigid cylindrical structure and a flexible spherical structure (see Appendix E for detailed explanation). Figure 4.4 indicates samples of the final illuminated form constructed during STEAM PL related to the research.

Figure 4.4: STEAM Lumifold project examples.

During PL, teachers discovered how 'flat to form' concepts can be realised and connected to biological and non-human technological forms. Figure 4.5 displays the glide reflection folding process.

Figure 4.5: STEAM Lumifold project.

4.3.2 Project 2 – Binary Bugs

Binary Bugs (BB) evolved from the workings of Lumifold. The project was developed as a way of including more mathematical content to the learning experience. BB was utilised in STEAM 2 and 3 with students, and in STEAM 4 as teacher professional learning. Like LF, BB developed as a method of exploring elementary symmetries in mathematics, with additional content related to probability, binary and biomimicry. Development of the visual design aspect of the project was based on understandings gleaned from a range of internet sources, such as PurpleMath.com (2017) . Other than exploring the base two numbering system and its relationship to the expression of binary numbers, the rest of the activity is unique to this study (see Figure 4.6). That is, all designed elements such as patterning and construction of the 'bug' were created specifically for inclusion in STEAM 2 and 3.

Figure 4.6: STEAM Binary Bugs project.

The BB project explores the complexity generated by interaction of two simple systems; a randomly created two-dimensional binary pattern and the structure of three-dimensional paper folding. The geometry of the 3D pattern embedded in the paper is enhanced by coin tossing to determine a 2D black and white (or colour/no colour) design. Hence the idea of binary merged with the mathematics of probability (see Figure 4.7). Similar to LF, the completed bug structure can be illuminated using LEDs. Detailed explanation of BB is located in Appendix E.

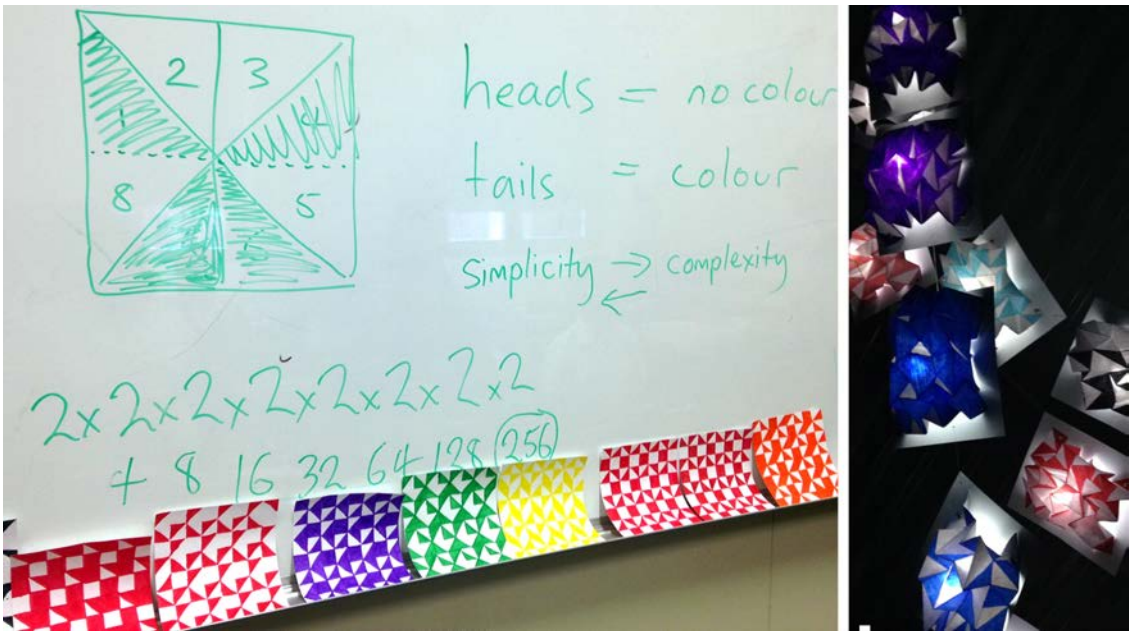


Figure 4.7: STEAM Binary Bugs patterning and final outcome (from STEAM 3).

4.3.3 Project 3 – Future Movers (robotics)

Future Movers was enacted in STEAM 1 only. The project is a conventional learning model related to robotics technology using Lego Mindstorms EV3™ kits. In STEAM 1, all participant teachers contributed to the creation of the activity in which the robots were programmed using a sequence designed to navigate a path through a so-called ‘city’ made from LF artefacts (see Figure 4.7). The project was named this ‘STEAM City’ at the public exhibition of student work from School 1. The title “Future Movers” encouraged teachers to consider pedagogy related to speculative futures. Futures in which the development of autonomous vehicles poses questions related to how we might navigate local and regional areas in the anthropogenic environment.

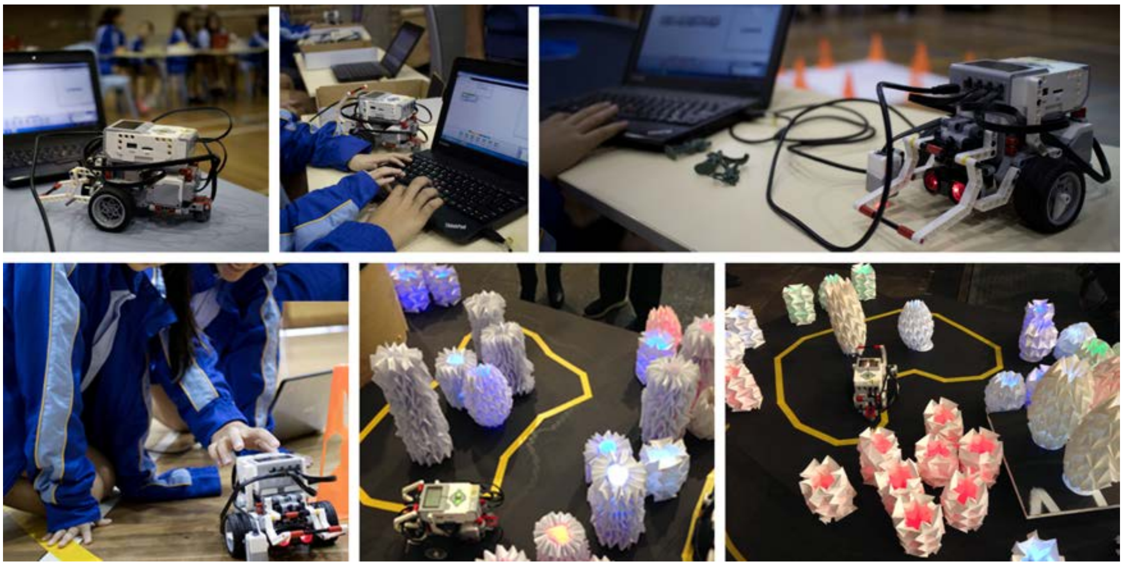


Figure 4.8: STEAM Robotics "STEAM City" project.

All teachers participating in STEAM 1 contributed to the construction of robotic vehicles during PL sessions in term 1, however the task of learning to program the robots was delegated to one teacher alone (see Figure 4.9).

Figure 4.9: STEAM Robotics PL at School 1.

4.3.4 Project 4 – Flextales

Flextales (FT) was a set of activities requiring the creation of a four-part visual narrative. Hence, the name of the project was 'Our Stories' in the case of STEAM 1 and simply 'Flextales' in STEAM 2. Flextales can be defined as a flexible product that tells a story. The FT project comprised the manipulation of a sequential set of images applied to a four-sided geometric rotating shape, generally known as a hexaflexagon. The shape is manipulated, or 'flexed', to reveal a story while rotating from one hexagonal face to the next (see Figure 4.10).

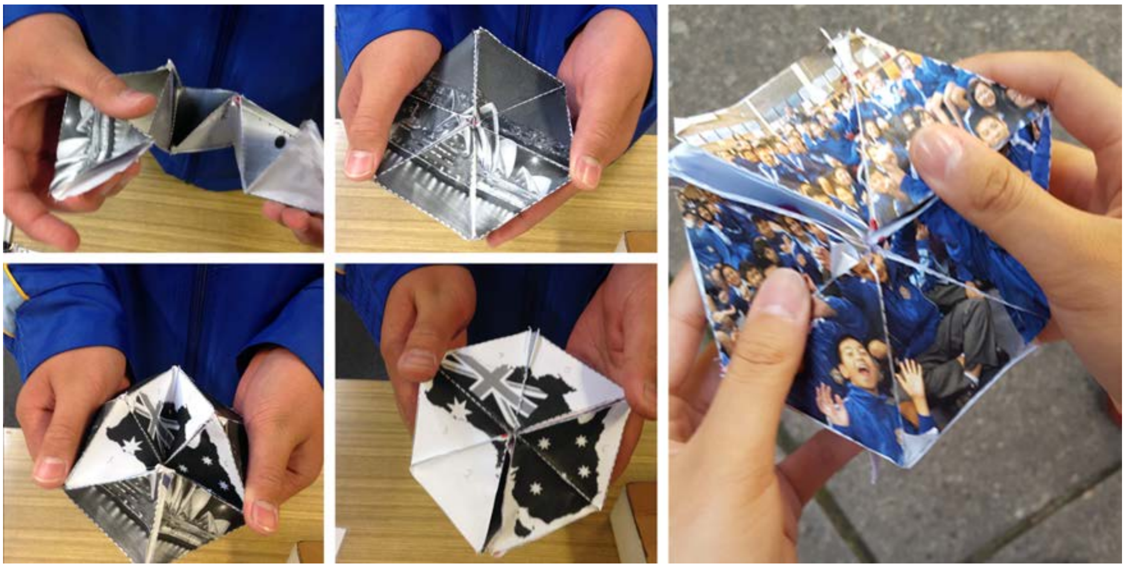


Figure 4.10: STEAM Flextales project prototype development.

The hexaflexagon design was not unique to this study, however its application as a sequential photographic narrative *was* new. Teachers in STEAM 1 in particular, contributed to FT iterations by way of investigating the mathematics inherent in the project. Much of the PL related to Flextales related to the physical properties of units made with equilateral triangles compared with isosceles triangles. The characteristics of such hidden geometries was perplexing to both teachers and students (see Figure 4.11). In addition to the mathematics, mapping digital images onto positional templates before printing and constructing was as challenging for teachers in PL sessions as in the project's delivery to students. Seven of twenty teachers participating in FT were mathematics specialists. However, the project melded rich literacy *and* numeracy components, providing opportunities for application over a wide range of subject areas.

Figure 4.11: STEAM Flextales teacher PL session.

4.3.5 Project 5 – This is Me (Augmented Reality)

'This is Me' (TM) was a project co-created for inclusion in STEAM 1. Teachers learned digital mapping, image manipulation and augmented reality (AR) techniques to apply in the construction of a simple poster design. The designed outcome displayed information about its creators (a group of four), abstracted into geometric shapes and text (see Figure 4.12).

Figure 4.12: STEAM 'This is Me' – perimeter mapping activity.

The design of TM was unique to the study, however the project made use of (then) existing digital platforms such as *Scribble Maps* (free online geo-location software), Adobe Photoshop, and online AR tools such as Layar and Aurasma (HP Reveal). Combining digital image manipulation with data visualisation, the project incorporated two methods of data representation and communication, requiring teachers to develop proficient digital skills, aesthetic sensibility and troubleshooting acumen, in order to facilitate efficient delivery to students. The mathematical content was related to area and perimeter calculations, coordinate plotting, and the creation of irregular polygons. The visual aspect required understanding of the elements and principles of design, with a view to producing an aesthetically pleasing 2D poster design. Figure 4.13 demonstrates how hidden information about the poster's creators was embedded into the 2D designs using AR, accessible via the appropriate app during the project exhibition.

Figure 4.13: 'This is Me' STEAM project design and demonstration of AR at exhibition.

TM was co-created with fourteen teachers representing various disciplines/faculties from School 1. Over two years of data collection during the STEAM PLB immersion, 246 Year 7 students contributed to 'This is Me', resulting in two versions of combined STEAM 1 perimeter maps collated as data visualisations seen in Figure 4.14. When accessed through a specific AR app on a smart device, these images triggered an overview video document of the STEAM projects at the school, an alternative to the individual stories related to students accessed by their group data maps.

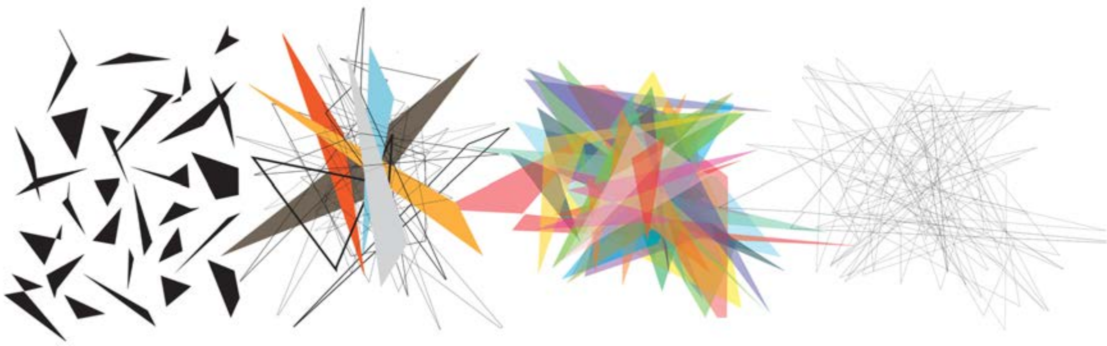


Figure 4.14: Data Visualisation – 'This is Me' projects over two years.

4.3.6 Project 6 – This is Us (coding and programming)

'This is Us' (TU), was developed as a follow-on project to 'This is Me'. Specific to STEAM 1, where the overall STEAM program was based on a PBL question of "How might we better connect with our community?", TU involved the creation of a scripted story, recorded and animated using coding. All teachers in the STEAM team were introduced to 'block coding', the model of learning devised for TU. However, the task of developing a detailed unit of work related to Scratch™ coding and Makey Makey™ was relegated to one teacher, expressing the intention of building coding technology into regular curriculum planning outside of the Year 7 STEAM PBL immersion. Collective PL was useful in devising strategies to scaffold and break down any coding issues into manageable parts, including how to organise and manage digital files logically, interpret numeric data and design and implement algorithms to solve problems. Teacher discussion during PL was largely associated with transitioning themselves (and students) from participants in a purported 'knowledge economy' to an 'automated economy'. Coding and interface images in Figure 4.15, display TU as providing teachers with activities guided by Year 9 students during PL in STEAM 1. Such PL afforded teachers understanding of contexts in which 'This is Us' enabled students to personalise their programming skills, and provide a range of experiences for the audience during the exhibition.

Figure 4.15: ‘This is Us’ STEAM project PL, student participation and audience engagement.

4.3.7 Project 7 – Hyperbolic Paraboloids

STEAM Project 7 was a paper engineering experience in which the transformation of a flat piece of paper into a three-dimensional shape is extended to create a range of polyhedra. Teachers in School 2 participated in PL to co-create an activity for inclusion in the Year 7 ‘Numeracy Day’, pre-empting the rest of the STEAM program. The Hyperbolic Paraboloid (HP) project was not enacted in other case studies. The activity was included in the research due to its combined numeracy and literacy inputs, and its effect on the participating teachers. Related to techniques used in Lumifold and Binary Bugs, the ‘flat to form’ experience transforms the paper material into a representation of the mathematical shape combining two conic sections: hyperbola and parabola. The shape is recognised as both hyperbolic paraboloid or parabolic hyperboloid. The HP shape represents an infinite surface in three dimensions. It has both hyperbolic and parabolic cross sections. It is a tactile way of introducing concepts related to abstract mathematical theory, as well as plotting, graphing and parametric variations in mathematics (see Figure 4.16).

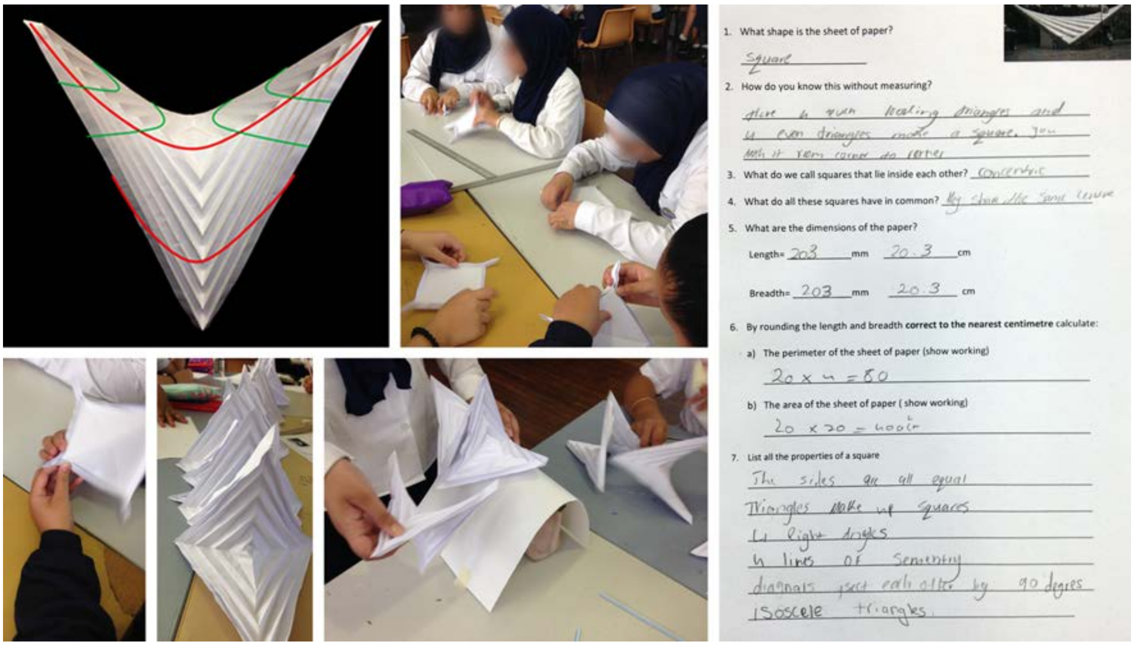


Figure 4.16: STEAM Hyperbolic Paraboloid project.

Singular or united, the properties and characteristics of the HP shape provided scope for a variety of making applications that were both intrinsically mechanical and conceptually metaphorical. The activity offered rich STEM content with tangential STEAM possibilities (see Figure 4.17).

Figure 4.17: STEAM Hyperbolic Paraboloids used in hat designs for STEAM 2 Numeracy Day.

4.4 Theoretical Commitment to STEAM

Focus area one presents evidence of the pedagogical complexities inherent in developing STEAM learning ecologies with a view to implementation in traditional educational settings. The sub-themes presented in this chapter present findings from the data related to challenges and limitations facing the transdisciplinary nature of STEAM, the relevance to real-world learning, and the sustainable potential of the STEAM programs enacted in the research. Each sub-theme finds supportive data through research observations and critical interview segments extracted from teacher reflections, leading to the identification of a range of teacher 'traits' emerging within the STEAM PL experiences.

4.4.1 The challenge to STEAM commitment

In field research, specific teachers from each case study provided rich evidence of theoretical commitment to understanding transdisciplinarity through a STEAM learning approach, including a fearless use of technology. This was particularly evident in STEAM 1 where the teachers were constantly encouraged by good-humoured STEAM PBL Coordinator: "*Open up that file, man… this is what the kids are expected to do!*". However, challenges to STEAM were not always expressed in terms of technological literacy. The transdisciplinary nature of STEAM emerged as conducive *and* problematic in situations where teachers were faced with extremely unfamiliar learning tasks. A pre-survey of 37 participating teachers revealed 73% had no experience of STEAM, although many had knowledge of the *STEM* acronym. Further data suggested that in theory, most participating teachers perceived STEAM as concerned with connected pedagogy, and the purpose of STEAM being to increase connections between subjects in order to lift overall student engagement (see Figure 4.18). In reality, STEAM was not for everyone.

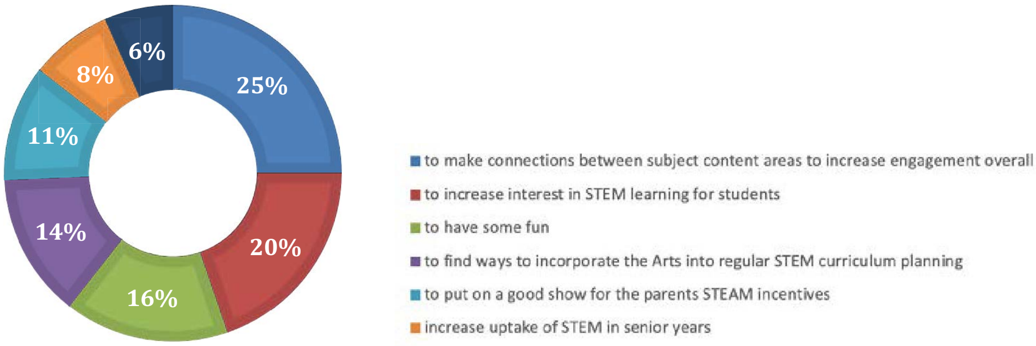


Figure 4.18: The purpose of STEAM – teacher survey responses. (n=37)

It is important to distinguish that my interpretation of reduced teacher commitment was observed in situations where participating teachers had not attended 3T6 STEAM PL sessions, manifesting in comments such as “*This project was too hard for the students. It was too hard for me”*. Counter to acknowledging such harsh realities, were abundant comments representing how “*It is important to view the Arts and Humanities* 1P *integration with STEM as connected knowledge”*. The challenge in answering the research questions was inherent in analysing perceived superficialities in teacher responses and bring the study back to its mathematical emphasis. STEAM 2 lead teacher expressed her STEAM learning as an “*expanded and renewed understanding of how* 2T1 *maths underpins every part of life”*. In contrast, participating teachers with expertise in knowledge areas other than mathematics, traversed unfamiliar territory during the attempt to seamlessly transcend discipline boundaries. For example, when teachers in STEAM 2 and 3 participated in PL to learn the process of creating the Binary Bugs STEAM project (BB), it was noted that scientific inquiry related to the concept of biomimicry was entirely new to them. However, it was agreed that *“even though this biomimicry concept* 3T1 *is new, we must include this angle in our STEAM program”.* The unique content within BB (see 4.2.2) in particular, was said to be unlike any PL in which the teachers had previously participated. For this reason, approaching STEAM PL from the perspective of transforming pedagogical design gave way to more nuanced personal and professional changes, evidenced in the data through interview comments during and after STEAM PL or program delivery, and summarised here by the Principal from STEAM 1: *“We can’t* 1P *just continue to operate in the same way as we have always done. Although the teachers* *here are very committed, very dedicated teachers, they are not risk takers and the biggest obstacle I have is resistance to change".*

Findings in the data presented noticeable individual teacher apprehension underlying the perceived collective commitment to STEAM learning. For example: "*In the beginning I was confused because I was trying to grasp the whole idea and then after* 2T3 *that I start asking my question where does this actually lead or link to the curriculum? I was doing that and what's the final product? What am I really trying to achieve?"* Negotiating different attitudes held by teachers towards developing integrated STEAM learning frequently queried *what are you trying to achieve?* in terms of the research questions and my own participation in the study. Certain participating teachers were trying to achieve a balanced approach to connecting content from disparate subject areas, holding views such as *"I don't think anything is isolated*", and others were simply 1T2 interested in having some PL fun (see Figure 4.18), expressed as "*We never get to have* 3T7 *fun in professional learning"*. What emerged from the data was that many types of teacher opinions related to STEAM were present, contributing to the interrogation of how teachers began to explore other ways of viewing themselves, a key focus of the first research question. Certain teachers saw the human inquiry characteristic of transdisciplinarity as potentially powerful in STEAM learning. Likewise in STEAM 4, interview data suggested that the transdisciplinary approach introduced in BB PL was considered a dynamic departure from regular learning and teaching practice related to maths in particular. For example, the geometry and tessellation principles of a 'glide reflection sequence', were acknowledged by teacher participants positively as:

4T7

> *"Relating biomimicry to probability to physical and functional qualities is coming back to some very simple mathematics. It could be used to demonstrate other parts of maths very well, binary for example. So many questions. So many concepts."*

4.4.2 The positive effects of transdisciplinary STEAM PL

Such comments suggested BB STEAM PL (see 4.2.4) represented how the idea of building knowledge connections from multiple perspectives was received favourably by the participating teachers. In this case, such a dynamic departure from conventional mathematics teaching was a positive experience, addressing the activity emotion aspect of the second research question. The challenge facing participating teachers in STEAM

4, was how to deliver the same type of learning to their students. The data suggested that teachers in this case might simply transfer the positive experience rather than directly deliver a BB project: *"What you provided was a unique learning experience, not* 4T3 *necessarily a lesson plan to take back to the classroom".* Similar to the challenge acknowledged in STEAM 4, teachers' theoretical commitment to make connections between subject disciplines across all the cases, was evidenced by a surfeit of note-taking and photographing during PL sessions. In addition, the teachers' lively cross-curricular discussions while making, for example: *"It's incredible isn't it?"*, afforded new understanding of STEAM concepts such as biomimicry. The data revealed positive effects of STEAM learning resulted in new understanding for teachers, often expressed in moments of teacher growth and transformation.

3T2 *"We're ready to grow the project. And more excited about developing and changing the ideas already in play to make the project even stronger from year to year."*

1T1 *"I love that we're trying. What I actually have huge respect for, for the people in this room, is that we're not afraid of actually just learning, you know?"*

1P *"My overwhelming response to the experience is that it was the best PL my teachers have ever had. The experience of the immersion program is that the learning curve was STEEP but so worth it."*

4.4.3 Relating STEAM professional learning to real world contexts

Another major challenge to STEAM PL was to identify its authenticity, namely, its relationship to real world contexts. For example, connections between biomimicry, automation, digital communication, and the hand-made were evident in all cases. The challenge was to relate such knowledge, skill and concepts to real world applications, 1P according to what the Principal from STEAM 1 describes as the need to: *"Deliver inclusive and supportive learning programs tailored to student needs to maximise their potential and to prepare young people for the world beyond school … and create a strong sense of belonging as I always believed this was critical to student success in schools from a disadvantaged community".* STEAM projects incorporating mathematical paper folding – Binary Bugs, Lumifold, Flextales, Hyperbolic Paraboloids – specifically brought content connections to the real-world front and centre to the delivery of each. In STEAM 1, all learning activities were related to the Year 7 PBL guiding question of 'How might we better connect with our community?', directly addressing the Principal's above comments. Data collected through two years of STEAM delivery to students at STEAM 1, demonstrated the effect of STEAM learning on broadcasting the innovation taking place at that school. Exposure of STEAM via public exhibitions of work resulted in increased enrolments to the school in subsequent years, and this trend is currently ongoing.

Similar data from STEAM 2 and 3, found teachers expressed appreciation of how the BB (see 4.2.2) making activity was important for 'their girls', identified through PL 3T1 conversations: *"Links to the real world are important for our girls"*, and *"It's not just the* 2T2 *making but the application is absolutely necessary".* In STEAM 2 and 3 PL, these facts were collectively acknowledged as contemporaneously applicable and relatable. Informal conversations recorded during first PL sessions in all STEAM cases generated the repeated question from participating teachers: *Why are we doing this*?. Teachers' own responses from Pre-survey data presented in Figure 4.18 from three of the four cases studies, was indicative of semi-definitive answers to that question. The data exposed individual teacher motivation was based on the desire to learn more about connecting STEM content with the Arts, in order to increase students' interest in STEM learning overall. While quantitative data do not specifically indicate teacher motivation to increase links to real-world contexts, interview data supported such pedagogical imperatives. An example from STEAM 1 Principal saying:

1P

> *"We were still implementing the new Australian curriculum with its focus on skills, general capabilities and an increasing awareness that we needed to change the current curriculum radically if we are to meet the needs of young people in the 21st century.*

Responding to the widely broadcast education needs above, teacher participants across STEAM 1, 2 and 3 expressed considerable interest and motivation to 'know more' when asked 'How open to this type of STEAM project are you?' (see Figure 4.19).

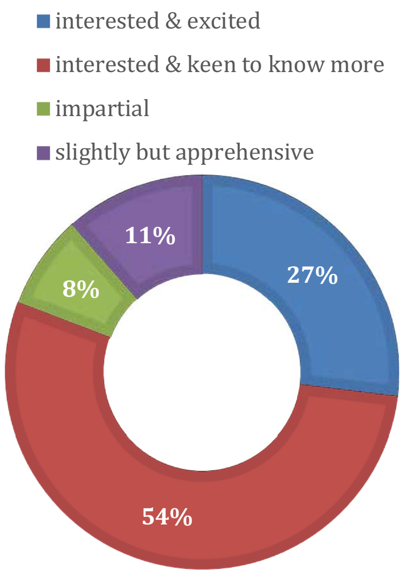


Figure 4.19: Pre-survey data. (n=26)

STEAM 2 provided more general evidence though qualitative methods, acknowledging the importance of real-world connections, for example: "*The mathematical part of it: equilateral triangle, hexagonal shapes and how the six ones can be used nicely, in real life things*". STEAM 2 data also indicated the prospect of STEAM PL and its relationship to the real-world does not excite and motivate everybody. Lead teachers in STEAM 2 expressed the necessity for connections to continue being built beyond STEAM learning instances, to emphasise real-world understandings. Comments from the data revealed that certain teachers were not enthusiastic about such requirements. Indeed, a proportion of teachers themselves did not show keen interest in supporting STEAM in regular mathematics classes:

2T3 *"We need to keep reminding them [the students] of connections, yeah. We need to remind them. Maybe you can find a few kids who are really smart, you see, they can see that, they will know that this is hexagonal [indicating Flextales]. Maybe they cannot express it but they know this is triangles but er…"*

2T4 *"They're noticing…"*

2T3 *"… for the majority of the students, we need to indicate that to them".*

Comments such as the above, combined with other qualitative methods used to collect data throughout the study, afforded me the opportunity to observe a large range of teacher behaviour, opinion, and reflection related to STEAM learning. It emerged from the data that I could not make assumptions based on observation alone. What appeared to be taking place, upon reflection, or formal interview with teacher participants, often differed with underlying attitudes and beliefs that were forming in the minds of the teachers. Such contrasts led me to create a list of teacher 'traits' to be aware of during consequent PL sessions and in particular, in the delivery of STEAM learning to students in STEAM 1, 2 and 3. It was important to recognise that my observation of teachers' actions frequently contradicted the way they were actually feeling.

4.4.4 The emergence of teacher 'traits' in STEAM PL

Good-humoured characteristics or teacher 'traits' began to emerge across all STEAM PL sessions conducted for the study. Each case presented with versions of the same 'trait', generally observed through PL sessions involving making. What I mean is, when teachers were using their hands to make something (see LF, BB, FT, and HP projects: 4.2.1 – 4.2.4). Frequently, the traits emerged within the context of collegial banter, often self-
3T5 nominated; *"you're such a neat freak",* for example. The categories I have devised for identification of the teacher 'traits' are not related to existing education research, other than the category of the 'Edupreneur', a hybrid term constructed by Tait and Faulkner (2016) in research related to teacher-led innovation in schools. Observational data collected across all four case studies revealed the teacher traits to be:

the neat freak – exhibiting the desire to complete the activities without making mistakes or deviating from the guidelines, both physical and temporal. (STEAM 3 and 4)

the bull at a gate – sacrificing quality for speed, whose race to finish values completion over measured pockets of understanding.

the formula maker – one who needs to plan and sketch before application, applying all the rules step by step with the aim of working out ways to make the process seamless for the students.

the nervous perfectionist – one who wants to get it right, can't stand mistakes, is usually silent and doesn't want to ask questions in front of the group.

the panicker – hysterics to start, panicking about everything but then coming up with well-constructed, thorough resources and solutions perfectly aligned with the needs of the students.

the resister – one who will never come on board, who will potentially never 'buy in' who actively opposes involvement. Behaving ambiguously.

the saboteur – places obstacles in the path of achievement, theirs and students', ultimately considering the activity to be of little or no value to teaching and learning.

the edupreneur – excited co-creators, exhibiting all the hallmarks of the innovator: willing to play, and are openly curious, visibly passionate, and fearless in the face of resistance. These teachers are committed to a collective purpose.

The characteristics described above do not aim to represent a definitive list of teacher traits. Rather, they acknowledge the shared human characteristics offered by the teachers themselves, and interpreted through research observation. While the teachers' overall theoretical commitment to transdisciplinary learning through STEAM was exposed in the data, certain obstructive hallmarks prevailed: *the neat freak*, *the bull*, *formula maker*, *nervous perfectionist*, *panicker*, *resister*. Notable patterns related to acknowledgement of the 'traits' emerged as signifiers to the emergence of *the edupreneur* in STEAM 1 and 3 in particular. In these cases, *the edupreneur* attribute aligned closely with STEAM learning objectives outlined by the program goals, neatly expressed by STEAM 1 Principal: "*Students [here] begin their journey towards being*
1P *young entrepreneurs through experiential STEAM projects where they learn design thinking, critical and creative thinking, teamwork and communication skills"*. Playful entrepreneurial characteristics displayed through STEAM teacher behaviour were seen to be interpreted by the students in Schools 1, 2, and 3, as creative encouragement to think differently about their teachers' identities and capabilities. For example, two years beyond the delivery of STEAM at School 2, Ms.SV revealed in a follow-up interview:
2T1 "*Those students still stop me in the corridors to talk about the Year 7 STEAM program. They're in Year 9 now. It's like we achieved something really special together and they feel it too*". Such comments indicated a dual value of STEAM learning experiences. A sense of transformation existed both in terms of how teachers viewed themselves, and how students viewed their teachers. In essence, the shared STEAM experience (teachers and students) contributed to the journey desired by the Principal from STEAM 1, responding to the question asked recurrently throughout the research: *Why are we doing this?*

4.4.5 STEAM teacher PL hand-making challenges

That question was never more prevalent than in the STEAM PL activities involving mathematical paper folding. Data collected through Experience Sampling (ESM) demonstrated the similarities in teacher experience across all cases undertaking the Lumifold project in STEAM PL. In contrast to ESM data collected in the initial STEAM 1 PL sessions, (see Figure 3.11 on P.#), which showed teacher responses to the overall STEAM learning program proposal, Figure 4.20 represents ESM data collected from participating teachers in STEAM 1, 2, 3, and 4, settings in which LF (4.2.1) or BB (4.2.2) were enacted. The total number of respondents was 47. It emerged from the data that 'challenge' was the primary emotion or state being felt by teachers during either LF or BB STEAM activity. Attempting to measure the value of teachers' activity emotions in regard to the second research question, ESM proved to be an appropriate quantitative data collection method. Figure 4.20 represents the aggregated ESM data. Each setting produced similar results in that teachers primarily described their emotional state during making as 'challenging', followed by 'engaging', and 'fun'. Such results coalesced with teachers' responses to desired outcomes from STEAM PL (see Figure 4.18), in which 16% of 37 teachers expressed the wish to 'have some fun' in STEAM PL.

Figure 4.20: ESM data related to STEAM LF and BB activities. (n=47)

ESM related to how teachers responded to learning through making in LF, BB, HP and FT projects was not the only method applied in data collection associated with teachers' experience of activity emotions during STEAM learning. Certainly, the use of mixed methods has resulted in quantitative support for what can be described as a rich set of qualitative findings. In relation to teacher challenges, the findings show that challenges were many and varied. Each challenge presented in the form of characteristics or traits, contributing to the categories of the aforementioned 'teacher traits' identified in the research.

4.4.6 STEAM teacher PL digital technology challenges

It emerged in the data that confusion over collaborative STEAM content surfaced parallel to anxiety related to technological skill. *"It's been a while since I've done* 1T5 *anything outside of my classroom"*, and *"We don't use technology much in our area. So* 1T9 *I felt like I was taking a risk in putting my hand up for this project*" expressed such concerns. Risk, in terms of teachers' using digital technology, presented as the most extreme challenge to achieving successful transdisciplinarity in STEAM 1 and 2, expressed vehemently as: *"If we can pull this off, it will be a bloody miracle!".* The 1T1 exclamation was interpreted as a very real understanding of the potential for failure in STEAM 1, due to the vast amount of learning required through PL in order for teachers to successfully implement the STEAM program with students. Interview data suggested collective perseverance and collaboration were key teacher desired attributes during the overall development and delivery of STEAM in all cases. For example, the inclusion of robotics shaped several transdisciplinary conundrums in STEAM 1, due to limited teacher experience or exposure to robotic technologies. Specifically, the challenge was how to meld this type of technological learning with the STEAM PBL model, including production of an aesthetic outcome for exhibition. In this research instance, the data revealed how the *panicker*, *resister*, *formula maker* and *edupreneur* solved the problem collaboratively. The group of teachers brainstormed various connections between STEAM projects that produced a material output, resulting in the exhibition of LF products as a city (see Figure 4.8) within which automated vehicles would negotiate obstacles (the buildings) using sensors (see details of STEAM City project in Appendix E). It is important to note that robotics technology was included in STEAM 1 only. Flextales STEAM project, however, enacted in STEAM 1 and 2 provided cross-case data related to the incorporation of digital technology in physical making. Participating teachers had little or no experience in either (see details of Flextales project in Appendix E).

The research data indicated that teacher perseverance, expressed through purpose or intention was the single most driving force in facing STEAM learning challenges. Digital upskilling and troubleshooting issues related to technology, emerged in the form of professional anxiety, particularly in STEAM 1 and 2. In STEAM 1, Teacher 5 explains, *"I hadn't used Photoshop for a while so that was a challenge, and I never used* 1T10 *Scribble maps before so I was curious to see how to fit these together".* While similar curiosity was evident in STEAM 2, the overarching response to using digital technology was perforated with teacher anxiety. For example: *"Yeah, I had anxiety… over… the* 2T1 *stupid Photoshop. Because I hadn't done Photoshop, with* strong interjection from 2T2 Teacher 2: *"**You** had anxiety! **I** had anxiety,* (facing me), *I had **major** anxiety when she goes 'excuse me I've never touched Photoshop in my life'"*. Learning digital image manipulation skills using industry level software posed large challenges for the teachers in STEAM 1 and 2. However, the data showed small transformative shifts in teacher attitudes as the projects progressed. Research instances collected through observation showed teachers' initial self-perception generally manifesting as 'I won't be able to do it', eventually giving way to teachers' understanding of commitment to STEAM learning in theory, warranted *actual* learning in reality. That is, learning in new territory situated in a set of unfamiliar circumstances taking place over a period of time. STEAM 1 Teacher 10, reflecting on her role as lead teacher of "This is ME" after two years of delivery to students, expressed: *"Last year I thought oh my God, but this year, on a personal level, I'm confident.* And in STEAM 2, the persevering teachers expressed how they met such challenges head-on: "*But once I did it I was fine, you know*", and "*I think that we did a better job being the novices…"*.

Challenge expressed through interview comments from STEAM 1 suggested commitment to digital learning in STEAM was aligned not only with individual skill building, but also the collective construction of skill and knowledge related to the STEAM project overall: "*if I was going to teach the others (STEAM team teachers), I needed to* 1T5 *know what I was doing".* Teacher knowledge of what they were actually doing was when STEAM PL evolved into a sense of ownership at School 1: "*And when they're [students] talking, I can relate and identify with what they've got to say, you know, about what* 1T10 *we're doing in Photoshop".* Challenge in the transdisciplinary nature of STEAM emerged in many forms and was observed as temporally influenced. The above comment was 1T1 noted as *"a dream day for Ms.ES*", where new transdisciplinary capabilities were incorporated into the teacher's personal characteristics and pedagogical skill set, resulting in situations where new programs of learning were potentially developed as 2T1 *"a spin-off from what we did"*. Thus, the data demonstrated how being technology novices evolved into teachers' acceptance of STEAM as important in developing innovative pedagogy. Nuanced evidence of teachers' transformed sense of self due to STEAM technology challenges was confirmed through comments such as:

> 1T1 *"We need to innovate, that's why we're doing this".*
>
> 1T6 *"I really want to know how to troubleshoot and solve problems with the software on my own".*
>
> 2T1 *"We're going to back those skills because they [students] need those skills".*

4.4.7 Teacher resistance or engagement?

The *resister* teacher type was generally observed during hand-making activities in the STEAM PL sessions. However, closer examination of the data revealed shifts in teacher resistance, mainly due to teachers' individual construction of knowledge supporting the mathematical foundation of the making activities. Interpreting silence as resistance during observation of PL sessions in all cases, was an incorrect assumption. Closer investigation of photographs from field work revealed a profusion of notes taken by those teachers perceived as resistors. Figure 4.22 presents a sample of teacher notes taken during STEAM 4 PL, and is representative of the types of notes taken by teachers in all cases where the Binary Bugs project was enacted (see Appendix E for more detailed content description of BB).

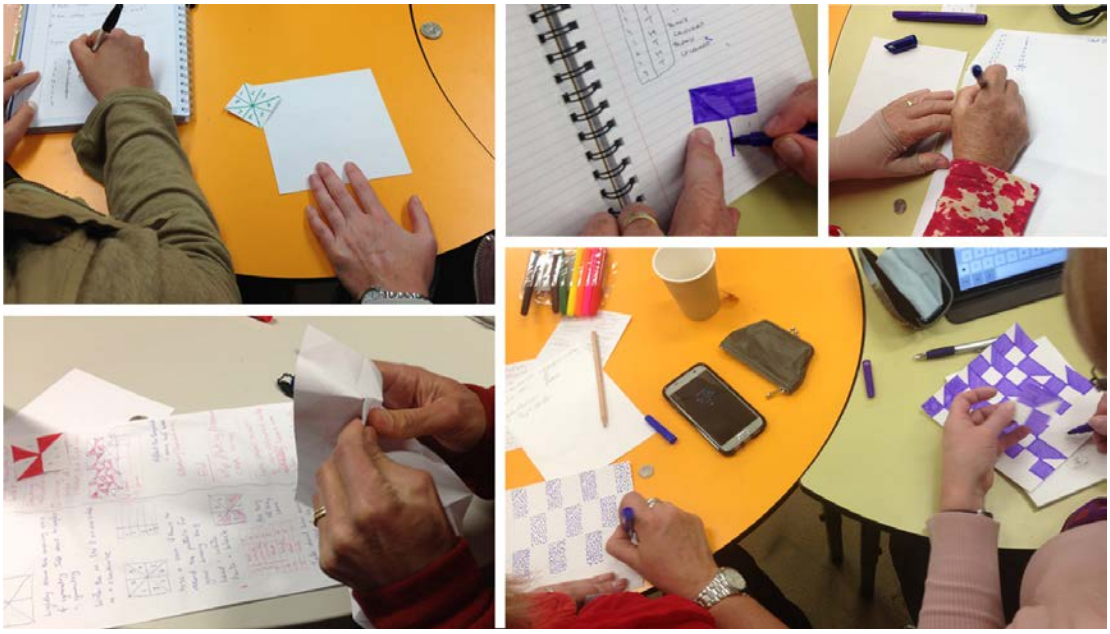


Figure 4.21: Teacher notes taken during STEAM 4 PL.

In STEAM 3, several teacher participants remained silent throughout the colloquial banter generated during the perplexing binary patterning and geometric construction aspects of the BB (4.2.2) activity. One in particular, made no eye contact, took no instruction, and rejected assistance, preferring to make detailed personal notes (see Figure 4.21), in the attempt to work out the pattern/construction alone.

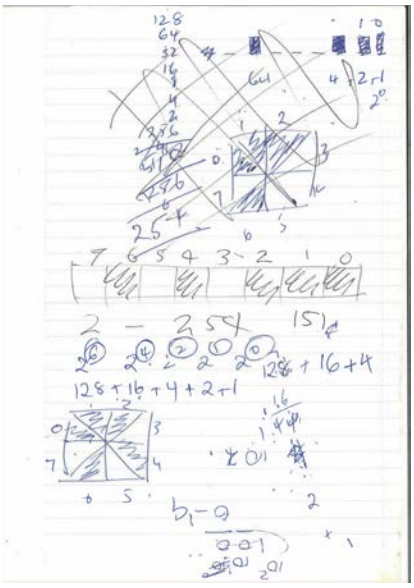


Figure 4.22: Teacher notes from BB in STEAM 3 PL session.

Still, bearing in mind the research being centred around phenomenographic human behaviour and as such, observation of active non-inclusion during PL may be interpreted as resistance *or* engagement, a personal demonstration of perseverance. Teacher

perseverance, in the face of challenge consistently presented variations of the *formula maker*, *nervous perfectionist*, or *neat freak* in STEAM PL. Teacher detachment might have also indicated individual fear of failure, or a sense of internal panic. In STEAM 4, teacher participants were more vocal in their expression of anxiety related to BB (4.2.2), for example: "*You made us feel like we are really dumb*". Group reflection from STEAM 4 revealed conflicting experiences for participating teachers. Several considered the mathematical content to be 'over their heads', increasing a feeling of insecurity based on the perception; *"[they] should know these things"*. While the mathematics inherent in BB was not beyond the capabilities of trained maths teachers or generalists in all cases, application in the arts/design context posed its own challenges because of the visual (non-numeric) nature of the activity. Frustrations, for example, were expressed
2T2 as: *"My fine motor skills but, seriously!"*, and *"I was like, what's going on, I had one right in front of me, and I still couldn't do it"*. The *panicker*.

The data presented unique instances of perceived teacher resistance, proving difficult to interpret. Decoding teacher behaviours in all cases exposed interesting dynamics between STEAM team members and teacher peers. In post-delivery interviews, further contradictions were found in teacher comments, offered by the participating teachers themselves or as peer evaluation. Frustration was voiced in STEAM 2, by teachers speaking of resistant peers during the delivery of the BB (4.2.2) project to students: *"He's telling them all the wrong things even though he knows it's
2T1 wrong. It's sabotage. He doesn't want to do this project… he sees it as not useful"*. The *saboteur*. However, it emerged from the data that the saboteur was indeed extremely interested in the concept and content in BB: "*Like the Bugs, how the diagonals and all
2T3 of this marking on paper and then flip it and it comes up with the bug. I mean, the whole idea from scratch, the person who actually invented that, how would they think that? This question was always in my head, how do people come up with this?"*. Observational evidence in the data, however, suggested much of the teacher's behaviour during STEAM delivery to students actually corresponded with his peers' description. A saboteur. The contradiction, therefore, resides somewhere between resistance and engagement for this type of teacher.

Similar data emerged in STEAM 3, where resistant teachers reluctantly
3T8 participated in the delivery of BB to students, professing: *"Why didn't you just get her*

(ie. the researcher) to do it?”. The nervous perfectionist. The neat freak. Analysis of this instance acknowledged how many participant comments were expressed through anxiety related to ‘getting it wrong’ such as: *“I’m crap at this!”; “I’ve never been any good at this type of thing”; “Yours is so neat, mine is awful”; “I can’t see what I’m meant to be doing”; “It won’t do it (the paper)”; “This is too hard for our girls”.* Interestingly, in contradiction to comments from Teacher 8 in STEAM 3, was data demonstrating her proficient conveyance of BB STEAM learning to peers at the annual conference for members of a registered mathematics professional association. (see Figure 4.23). An interesting observation recorded during the Teacher 8’s presentation, was the representation of teacher traits in the conference breakout audience. Teacher 8 was in a position of navigating such traits in order to successfully deliver BB PL herself, paralleling her own experience of BB PL at the beginning of the research. Teacher 8 responded to her audience of peers, revealing transformative expressions of empathy:
3T8 “*When I first tried this, I couldn’t do it. You’ve gotta be patient, you've gotta… don't turn your back on it”*

Figure 4.23: STEAM 3 teacher presenting BB to peers.

Perceived resistance observed in STEAM 1 was also reframed as persistence through data analysis, exemplified by attitudes such as: “*We are going to run with this*
1T1 *even if it fails”.* As the STEAM programs progressed in STEAM 1 and 3 in particular, the data showed marked increase in teacher motivation and appetite for success. Iteration of the STEAM programs at School 1 and 3 into subsequent years, presented further opportunities to observe how former perceived ‘resisters’ relented. The ebb was largely

due to the success of the STEAM programs, identified by the Principals in STEAM 1 and 3P 3 as “*surpassing all expectations*”. Data recorded in formal post-delivery interviews in STEAM 1 demonstrated how

1P
> *“The experience was overwhelmingly positive and affirming. The experience had immediately strengthened my relationship with students, staff and parents, in particular for the group of teachers associated with the community project exhibition. It’s also affirming and positive when we see connections between exploring a range of knowledge and modalities in teaching”.*

Such comments provided evidence of how temporal influences assisted teachers to face the challenge of new STEAM pedagogy, leading to a better understanding of transdisciplinary learning and teaching practices, as well as their influence on students and the wider community.

The findings show little difference between cases in which participating teachers were regarded as ‘conscripts’ (STEAM 2 and 3), rather than volunteers in STEAM PL. It would be wrong to interpret the many silences observed in teacher staff meetings and PL as resistance. Indeed, the silences demonstrated certain professional anxiety, which, as the data indicated, dissipated over time. In essence, the narrative presented in STEAM 1 and 3 specifically, travels in accordance with phenomenographic transformation. While in STEAM 2 and 4, the findings demonstrate growth and expansion inherent in appreciative inquiry:

4T1
> *“I felt really dumb because I didn’t understand what was going on, and then I felt angry because I felt... this is like... this is not happening, but now I feel like the most accomplished person in the world!”.*

Similar responses were recorded across the cases, indicating small teacher transformations, interpreted the through appreciative inquiry methodology, within which disruptive innovations are viewed as essential to growing a generative set of practices (Cooperrider et al., 2013). Transformation was generally expressed when comprehension of what teachers’ were learning was translated into the item that they were making; Dewey’s (1938) so-called *erlebnis* – the ‘in-the-moment’ experiences. Many participating teachers expressed the desire to share their often emotionally charged erlebnis experiences out loud.

1T6 *Oh my god I get it!*

2T2 *My guys are going to be so impressed with me.*

4T2 *I'm so proud I made this!*

3T1 *This is incredible!*

I love this and our girls will love this too!

4.4.8 Sustainable potential of STEAM

STEAM PL and learning programs enacted in school locations in the research explored the relevance of transdisciplinary learning for participating teachers and the school executive, with a view to providing STEAM sustainability. By sustainability, I mean the ability to plan and deliver future STEAM activities independently, in terms of school budget, resources and staffing requirements. Pre survey data in Figure 4.19 showed 81% of twenty-six teacher participants from STEAM 1, 2, and 3 were interested and motivated to know more about STEAM learning and teaching projects. Interview comments supporting this figure were also expressed across the three cases:

1P *"This new approach coincided with the rise of STEM curriculum. I wanted to learn more and understand how this could be a part of our curriculum, as it addressed future needs, and prepare students for increasing career options, where over 75% of future jobs will be in the STEM sector."*

2T1 *"We've been moulded into who we are by circumstances. We've never had the high achievers. We always lose those kids to other schools so we are trying to kind of build the other kids up by doing different things. We enjoy what we are doing and can see the successes".*

3T2 *"You know what we could do now…"*

When considering the likelihood of incorporating more STEAM ideas into future lesson design, survey data collected after STEAM delivery to students revealed a drop in levels of teacher excitement and motivation (see Figure 4.24). One third of twenty-six teacher respondents considered STEAM incorporation unlikely.

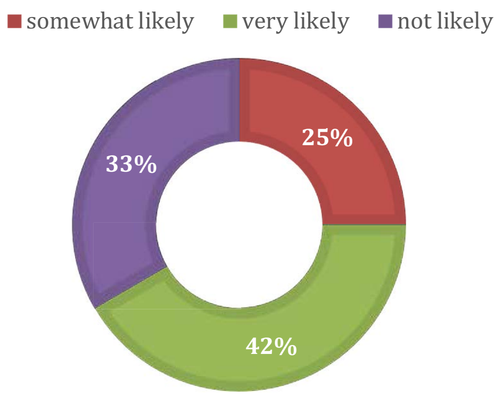


Figure 4.24: Post-survey teacher responses. (n = 26)

Further to the question of likelihood, participating teachers were also asked to identify their key needs related to continued embedding Arts approaches in STEM learning, and vice versa (see Figure 4.25).

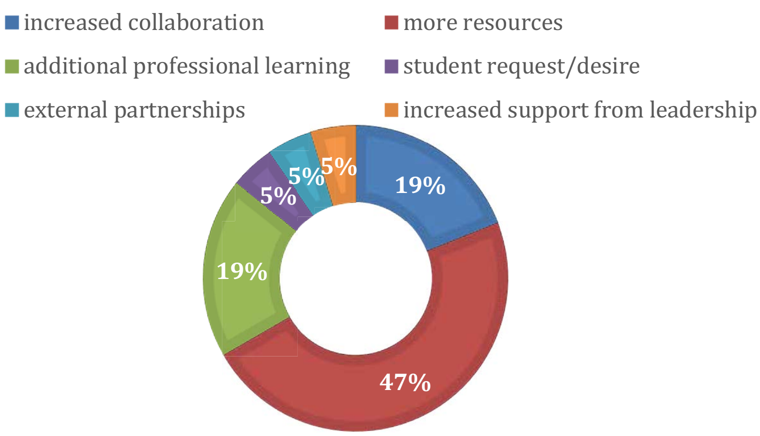


Figure 4.25: Post-survey teacher responses. (n = 26)

Regarding the first research question, 'How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves', the notion of ownership in terms of how to sustain PL in teacher practice was important. Evidence in data collected over two years of Year 7 and teacher immersion in STEAM 1 supported how aspects of the program moved STEAM pedagogy forward. And how the participating teachers relied on increased collaboration to support more STEAM resource-driven professional learning. Post-delivery interviews with the STEAM coordinator described the STEAM learning narrative (currently still evolving) at the school.:

> *“This year we actually had something amazing happen. It is a highly interdisciplinary project on its own, but this year we actually did have a STEAM week [before the program]. At this stage, I am not really sure how our staff or our team members were able to communicate this clearly with their staff and their faculties. Or whether they have actually seen everyone do it or not, but like for 5 minutes or 10 minutes, the attempt was made, so that all staff members taught [a bit of STEAM] for 2 weeks beforehand. That they did have to address in science, for example, electric circuits. You know, in maths, 3D shapes. What shapes are and in art I know they actually unpacked, what a good artwork looks like”.*

The aim of PL in STEAM 1, 2, and 3 was to promote teacher ownership of the STEAM learning. Participating teachers considered the achievements of their STEAM teams as “*quite phenomenal, the whole school has been exposed to what we’re doing”.* While Figure 4.24 suggests ‘additional resourcing’ was acknowledged as a major input for sustainable STEAM learning, there was also significant interest in increasing opportunities to collaborate with peers and additional professional learning. In STEAM 1, the data emphasised how the STEAM teacher team was motivated by collaboration, and how transformative the STEAM program was for these teachers from one year to the next: “*I particularly like that my STEAM teachers went and fought that battle with appropriate people themselves. Whether they won or not is not an important issue to me … I don't think the focus is that it actually alleviated work for me, but it is the group ownership.”*

The difference between tracking sustainability across the cases situated in schools was due to the range of STEAM projects undertaken, and the method of delivery to students. STEAM 1 and 3 chose an immersion model, while STEAM 2 chose periodical delivery over three school terms. One project, however, was enacted across the cases, therefore its potential for sustainability can be measured more broadly. The BB (4.2.2) project was chosen for delivery in both STEAM 2 and STEAM 3 due to its inherent mathematical foundation, balanced with scientific inquiry and hand-making experiences (detailed in Appendix E). Components of BB merged with LF (4.2.1) in STEAM 1, and BB was the single PL project enacted in STEAM 4. Figure 4.26 shows how the flow of teacher knowledge (top row) transferred to the collective student experience (bottom row) in the first BB experience from STEAM 3.

Figure 4.26: STEAM Binary Bugs project enacted at School 3.

Data collected across the cases, demonstrated how teacher capacity for engaging with transdisciplinary connectedness was sustained in a teacher attitudinal sense, yet the actual STEAM programs were embedded iteratively in STEAM 1 and 3 only. Nevertheless, it emerged from the data that small transformative moments occurred for the teachers who committed themselves ‘in theory’ to STEAM learning, frequently surprising themselves or simply re-discovering pedagogical talents that were lying dormant.

4 T4 *“I felt apprehensive at the beginning because this is completely new for me. But I’m looking for something to add to our repertoire. We have a section at the end of the year for Year 7, 8 and 9 called ‘unleashing your potential’. This would be fantastic for that. It’s very cool. So interesting”.*

1 T5 *“Firstly, I love meeting new people and working with new people and getting ideas from all over the place. As teachers we can not only learn from each other but from other professionals that have new and different approaches to learning. I love collaborating”.*

2 T5 *“… with my background of Literacy and English, a lot of the time when I think of Maths and Numeracy, I typically associate it with numbers. But we also need to think about the ideas behind… the numbers. But the thing you have done today is not just about ideas. The fact that it was a challenge, the fact that we all discovered something new, this was a big discovery, even for myself”.*

1T9 *"This makes me willing to try some more things even though I am the most technology illiterate person."*

3T4 *"There actually is enough 'real' maths. There are real and relevant connections between the specific STEM content and real-world applications. It's so visible when you do it*".

The transdisciplinary discoveries made by teachers participating the study presented both personal and professional views on how STEAM sustainability might be achieved, imagined speculatively by the Principal in STEAM 1: *"I would love to see it happening in*
1P *everyday classroom settings, not just in a big project. Even if it's a couple of lessons where two teachers are working together, you know, cos they've got the same class time".*

Section 4.3 provided an overview of the degrees of teacher theoretical commitment to STEAM professional learning. In effect, BB (4.2.2) presented the most well-rounded and balanced transdisciplinary STEAM project at the beginning of the study in terms of connecting STEM theory through an Arts context. What eventuated is that *all* of the STEAM projects grew into balanced and versatile learning activities, eventually owned and delivered by the teachers themselves. My role as both co-facilitator of STEAM PL, and participant researcher, stood concurrent with the primary aim of the study; to encourage acknowledgement of the A (the Arts), in order to increase teacher enthusiasm for authentic transdisciplinary investigation across STEM *and* the Arts. Co-facilitation required co-creation of resources in the form of succinct and informative instructions (Appendix D), providing support for the relevance of what we were trying to do. In my research role, I collected data relating to participating teachers' varied responses to all of the STEAM projects and activities. Participating teachers worked towards the collective purpose of connecting STEAM concepts to the real world, and transforming their own pedagogy to match. The data revealed a thirst for PL experiences that allowed the teachers to play, express curiosity, demonstrate passion, and embody fearlessness. The following section explores how such teacher thirst was quenched.

4.4 Physical and Emotional Commitment to STEAM

Physical and emotional commitment refers to how teachers experienced embodiment of STEAM learning at the hands-on level. This section of the chapter demonstrates how such commitment was tracked through the data related to challenge in STEAM learning. That is, through the expression of teachers' activity emotions; how the teachers *felt* while they were engaged in STEAM. Sub-themes emerging from this focus area are presented through the expression of activity emotions, specifically addressing the second research question: 'How do emotions experienced during engagement in STEAM activities enhance or detract from the teachers' professional and personal identity development?' A selection of teacher interview excerpts and observations related to teacher transformation are presented in this section through unmediated *in-the-moment* experiences, and reflections after STEAM PL sessions or delivery to students. Activity emotions are presented through Wagner's (2012) identified innovative learner attributes of play, curiosity, fearlessness, and passion. Analysis of the research data found such attributes emerging as key sub-themes in the study. Experience Sampling (ESM) and teacher survey data provided supportive quantitative results, working in tandem with qualitative data collected before, during, and after STEAM learning. Data collected across the cases considered the impact of emotions felt during individual moments of STEAM learning and the vital contribution that emotions make to understanding tacit forms of knowledge building, as well as those more explicitly transformative; for example: "*This experience has changed my life*."

4.5.1 The value of the 'aha' moments

Napier (2010) considers 'aha' moments are valuable to learning. Preceding judgement and influence, they presented frequently during erelbnis experiences for teachers partcipating in the study. The findings presented singular expressions of 'aha' as: "*Oh*
1T6 *my god I get it!",* and more reflective teacher comments such as, "*Wow, I didn't think I*
4T6 *could do that!",* and: "*The 'aha' moments were awesome to have as well as to watch".*
1T7 The teacher 'traits' outlined earlier emerged through the observation of 'aha' moments, simultaneously considered through the lens of play, curiosity, fearlessness and passion. Hence, the sub-themes in this section of research findings are presented through such attributes (see Figure 4.2). Data drawn from the focus areas indicated the potential that activity emotions offer as catalysts for changing the way teachers think about themselves and others. Correlations between each of the case studies revealed similarities in emotional trajectory when teachers were faced with experiencing and/or delivering many components of the STEAM learning. Teacher emotions were expressed

as joy, empowerment and care, together with anxiety, fear, fatigue and frustration. The data presented teachers' rich positive *and* negative visceral experiences, including pre-service teachers (PST) in STEAM 1 and 3. PST feedback was important to the research as it provided alternative perspectives to in-service teacher experiences. PSTs were new to the teaching profession, eagerly collecting insights and resources they might add to their own professional portfolio. Nevertheless, in-service *and* pre-service teachers were predominantly new to STEAM. Therefore, feedback in the form of 'Aha' moments was identical for all participants, and were best described as moments of discovery, central to the teachers' notion of play.

4.5.2 STEAM affords teachers permission to play with mathematics

The data indicated that play, particularly the mandatory playing with mathematics embedded into the STEAM activities, produced a range of emotional responses from participating teachers, ranging from expressions of uncertainty and/or anxiety, to joyful elation. Those who relinquished control to engage with the playful aspects of STEAM learning, permitting themselves to play, expressed greater levels of joy on completion of the activities, for example "*I didn't think I could do this!*", "*I'm so proud of myself*", or
3T2 "*This is incredible*", and "*When can I make another one?*" Such joyful moments increased
2T1 the possibility of transformation for the teachers as they constructed new knowledge
1T6 from unfamiliar contexts.

Mathematical concepts underpinning the STEAM projects were not new. However, playful application of maths to the creation of unique methods of knowledge construction *was* new. Teachers were required to visualise the maths by using their hands in new ways, often revealing "*for the first time in a long time*". Interestingly,
2T2 resounding comments from a range of post PL teacher interviews across the cases lamented the fact that PL was more than often unengaging.

1T6 "*We never get to make anything*"
2T1 "*We don't play in PL*".
4T6 "*We never do anything creative*".
3T4 "*We're always just sitting and listening, not making or doing anything*".

Such comments suggested that mandatory play had potential benefits to teachers' construction of STEAM knowledge. ESM data presented in Figure 4.20 supported the connection between play and activity emotions, particularly during PL including ‘making with mathematics’ (LF, BB, FL, HP: (4.2.1 – 4.2.4). In support of the quantitative results showing teachers’ experience of challenge as closely aligned with fun, group evaluations collected after STEAM PL delivery across the cases, established that peer-to-peer collaboration was most effective in developing teachers’ understanding of the maths-making tasks. The findings presented that teachers’ self-permission to play was frequently usurped by individual anxiety over ‘getting it wrong’, rendering the *bull-at-a-gate*, *panicker*, *nervous perfectionist*, and *neat-freak*, united in collaboration:

4T1 *“At the beginning when we were flipping and colouring, I felt ok. I felt I wanted to do it quickly though, to show I was confident but I wasn’t sure that I had all of the information I needed. So there was a bit of urgency, but then I relaxed... but then the folding happened and I got a little bit stressed and puzzled again.”*

4T2 *“…and then you helped me.”*

2T5 *“What if I can’t do it?”*

2T1 *“What if we do it together?”*

1T9 *“I felt like I was taking a risk in putting my hand up for this project, but the others have been really helpful.”*

1T5 *“I always like to give myself a bit of a challenge of giving something a go and learning something new and helping other staff to learn it too.”*

3T4 *“It’s so good to do something different to usual, and together”.*

Observational data showed how teachers’ emotional contagion created a web of intersecting experiences, tracking through interest, excitement, potentiality, nervousness, trepidation, anxiety, fear, risk, vulnerability, agitation, anger, resentment, perseverance, effort, concentration, engagement, achievement, joy and elation.
3T3 Comments such as “*That was the most refreshing PL I’ve ever attended”,* and *“Our students will love this”,* were frequently offered; plus, “*I can’t wait to show the students*
4T3 *tomorrow*”, or “*My kids are going to be so impressed*” (referring to teacher’s own
1T6 offspring), demonstrated how teacher collaboration nurtured manual *and* digital STEAM capabilities. The data showed that through collaboration, creative and playful collegiality emerged during all STEAM PL sessions in every case. Samples of such collegiality can be seen in Figure 4.27.

Figure 4.27: Participant teachers in STEAM PL – BB, LF and FT activities.

4.5.3 Playing around with ideas in STEAM professional learning

Data specifically related to the non-digital STEAM projects showed that using paper folding to 'play' in STEAM learning led to discussion of new models of pedagogy amongst participant teachers in each case study: *"So I'm also learning while playing around".*
3T4 Concepts inherent in paper engineering enacted in the STEAM activities, connected maths to real-world contexts such as biomedicine, astronomy, architecture, design and nanotechnologies. Such exposure served both teacher and student transdisciplinary knowledge construction in all cases, expressed overarchingly as *a great way to show maths concepts.* Unsurprisingly, the action of hand-making for the first time in a long
4T4 time, appeared to increase teacher confidence in trying something new, evidencing how permission to play in one context might be an effective conduit for playing around with ideas more broadly.

Playing around with ideas strengthened positive collegial relationships throughout the STEAM PL, resulting in much teacher discussion of knowledge connections and how to translate such connections during STEAM delivery to students. The idea of 'metaphor' emerged through conceptual play, realised through LF, BB and HP projects (see 4.2.1, 4.2.2 and 4.2.4). In STEAM 3, the excitement over the potentiality of Binary Bugs resulted in exclamations such as: *"We could make a 'swarm'. Imagine the*
3T1 *light show… 170 binary bugs!".* Generally, the data showed conceptual connections with

maths were made because the paper folded shapes "*look like something else*" when
2T5 formed in different orientations. In STEAM 2, the maths-making challenge was suitably explained to students through the idea of metaphor during the school's numeracy day:
2T5 "*I'd never really looked at this* (maths) *and the way it's so important in our everyday lives. So, what we're going to look at today is… metaphor. Who knows what metaphor is? Think into English now. Yeah?* Teacher 5 used her own experience of making a hyperbolic paraboloid as a metaphor for 'pushing through', attempting an activity in the face of perceived difficulty or impossibility. Teachers in STEAM 1 developed the same method while playing around with ideas during the challenge of making the flexible mathematical HP shape in STEAM PL (see Figure 4.28).

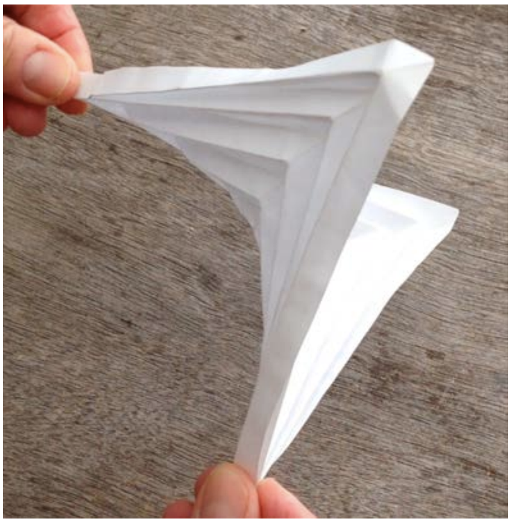


Figure 4.27: Paper representation of the Hyperbolic Paraboloid

In STEAM 1, the data showed teacher anxiety and apprehension were relieved through playing around with ideas in PL. Consternation arose in the form of repeated "*Why are*
1T7 *we doing this?.* Through collaborative brainstorming, teachers' disquiet gave way to "*Why don't we…*" or "*We could do this…*", in relation to connecting each STEAM activity with each other under the PBL guiding question. Specifically, playing around with ideas resulted in the teachers devising a method of combining mathematical paper folding with robotics technology and narrative construction in the Lumifold STEAM City and Flextales projects (see Appendix E).

Expressions of emotional honesty related to the STEAM learning experience frequently emerged in the data, often expressed metaphorically by the teachers
2T5 themselves: "*For me Mathematics is like jumping into deep water, it's scary at first but you have already been taught the basics of swimming and you can keep yourself afloat".*

2T5 Small transformations were presented either through PL experiences or during STEAM delivery to students: *"So, when we think of discovery, I discovered something new. I had no idea that the square could be made into something like that".* S2T5 is referring to the HP project. Her admission to students attending the Numeracy day in STEAM 2 was qualified by S2T1: *"It's exactly like what you've just said* [indicating S2T5]. *It's like flying a plane. It's really hard and you don't know how to do it but hey, we ran out of paper. We made 500. We had 500 sheets of paper and you lot were able to make 500 of these HPs. This is what you did. When you were able to do it, you flew through it. We didn't have to show you".* Such teacher/student exchange and shared pedagogical insights were only made possible through playing around with ideas in PL leading up to the Numeracy Day event. Playing, in terms of attempting and failing, then attempting again, was evident in much of the data collected even in STEAM 4. For example:

2T1

> 4T2 *"At the beginning um... I suppose I was a bit anxious that I did it wrong and I tried to imagine what the kids would be feeling and then collaboratively working together…"*

> 4T3 *"Yeah, feeding off each other and buddying up at the end and with positive feedback from our instructor* (the researcher), *we were reassured that we could do it. That reassurance gave me confidence and sort of allowed me to see that I could play around and make mistakes and it's ok. So I'm looking forward to doing this again at home and trying and having another go".*

Such examples from the data showed how pedagogical sustainability related to STEAM appeared dependent on collegial admissions of physical and emotional feelings. Teachers physically playing with new concepts, tools and techniques appeared enthused and excited, as well as doubtful, in respect of how new ideas, skill and experience was to be transferred to their 'kids' (the students).

4.5.4 Playing in a digital space to foster STEAM sustainability

Phenomenographic transformations in relation to the research questions were characterised by the aforementioned teacher 'traits', observable and relatable throughout physical *and* digital aspects of teachers' STEAM learning. Digital technologies were embedded into learning in STEAM 1 and 2, and the inclusion of such was critical to generating sustainability of the programs at those schools. It emerged from the data that most participating teachers were operating in activities far removed from familiar and expected teaching methods, where reliance on textbooks and handouts was normal practice. The data showed there was some panic related to such non-conventional teaching practice, evident in the repeated question from teachers in STEAM 1 and 2: "*Why are we doing this?*" The value in removing convention is described by teachers from STEAM 2: "*We can't rely on a textbook … and I have to say, the amount* 2T1 *of effort that [2T2] puts into coming up with ideas and activities to make things relevant, sort of inspires me to want to achieve because I don't want to let her down".* The value of enthusiasm when faced with digital challenges in STEAM learning was likewise expressed in STEAM 1: *"I'm so excited to be learning this stuff. I can see so many uses* 1T6 *for it in my subject and in others. I really want to know how to troubleshoot and solve problems with the software on my own*". The transdisciplinary nature of the STEAM projects enacted in the research belied the use of textbooks due to the projects' unique interactive and collaborative style of learning. Teachers recognised that their own emerging digital capabilities were not as much for themselves as for their students: "*it's* 2T2 *about the students, not about us. I will put in as much work as we have to do, for the kids to get something out of the project, you know what I mean? To make it different".* In this sense, some of the participating teachers were embracing the attributes of the *edupreneur*, often expressed with emotional vigour: "*My learning curve was like this!".* 1T8 This comment was offered unsolicited. A dramatic, and surprising gesture from a STEAM 1 participant teacher during the STEAM showcase held on completion of the program at the local retail centre. Swinging her arm vertically from the elbow upwards into the air, Teacher 8 was referring to the experience of learning Lego Mindstorms robotics technology for Future Movers project in STEAM 1 (see Appendix E).

Teacher transformation from *panicker* to *edupreneur* in terms of digital aspects of STEAM learning was revealed in the data, albeit only in STEAM 1. Apart from robotics technology, in STEAM 1 teachers learned skills in Augmented Reality (AR), videography, coding and electronics. Teachers in STEAM 1 and 2 learned digital image manipulation software to service four of the seven STEAM projects included in the research. The findings revealed that such learning did not occur without trepidation: *"I am the most* 1T9 *technologically illiterate person, so it did scare me when we did the first couple of PL sessions"*, and *"Last year I panicked, because if a kid was not there, I would panic. Oh my god, what the hell am I gonna do? But this year, I think if they're* [student helpers] *away, I can do it".* Fear and fearlessness associated with teachers' learning new skills is discussed later in this chapter. Digital troubleshooting capabilities were exposed early in STEAM 1 and 2 PL where the teachers' new competencies gained through persistence were enacted in front of peers and students, and in the case of STEAM 1, in front of parents and members of the general public, off-site to the school. For example, Teacher 1 described her colleague's digital troubleshooting skill earned through PL sessions in STEAM 1 as:

> 1T1 *"…just my saving grace that day. She came in the morning and matched off all the videos… except there was one kid. She [1T6] goes, 'I knew this would happen'. One kid brought a parent to exhibition and it was the wrong video embedded in the AR. Lucky that our system is where it gets transferred off to my iPad, right. So I had the footage, which was a good thing and [1T6] just uploaded it on the spot so that the parent could actually trigger the AR and see the right one. That was just troubleshooting. And she was great".*

STEAM 1 Teacher 6 demonstrated motivation and enthusiasm for problem solving, valid understanding of anticipated issues off-site, and certain fearlessness in her approach to STEAM pedagogy. Such transformation is a not-to-be-underestimated hallmark of the *edupreneur*.

STEAM 2 presented a different outcome in comparison to STEAM 1. While STEAM 2 lead teachers overcame panic associated with using new software related to the Flextales project, new knowledge and skill constructed via necessity was not on-shared with staff or students. Hence, the potential for STEAM sustainability was less at this location. In reference to peer teachers participating in STEAM 2, lead teachers 2T1 recognised that "*They do go along with it, there's no opposition or anything like that so it's good in that respect".* However, a certain protective element in the peer-to-peer relationship emerged in the data, expressed as "*I think anything new, anything that* 2T2 *requires a lot of work for them… it's too much, too much effort".* In this case, the digital component of STEAM FT project was deemed too much, as teachers had already been challenged by hand-making components of Binary Bugs.

4.5.5 Teachers' aversion to play in STEAM

If the participating teachers considered playing to be learning, then the data would not reveal any teacher aversion to play, unless teachers did not desire to 'learn' during STEAM PL. Yet the data did reveal nuanced moments of aversion, interpreted as specific 2T1 teachers' unwillingness to 'get on board'. "*Lack of initiative*" was expressed as the painful part of STEAM for lead teachers in STEAM 2. In combined post-interviews, the teachers admitted frustration with fellow staff members: "*instead of them saying,* 2_{T2} *'would you like us to teach ourselves how to do this?' 'Would you like us to get involved and team teach?' 'Can I team teach with you?' 'Can I have the opportunity to run this in* 2_{T1} *my class?'"* Teacher 1 interjected with *"but it's out of their comfort zone".* Data collected across the cases presented similar teacher comments related to frustration with the level of motivation or engagement from peers: *"This is a big challenge for some of the* 1_{T1} *teachers here. It shouldn't be, but it is".* Or lack of collaboration: "*They didn't want to play with us*"; or irritation with attitudes towards the STEAM content: *"Some of them* 2_{T1} *might feel a little bit hesitant because they think they're better than this project".* Individually, certain teachers questioned the authenticity of what they were learning, having little or no experience of STEAM. While transdisciplinary principles of STEAM are seen to be encompassing, the research findings suggested it was, at its core, challenging for the teachers in these case studies: *"Starting with the presentation, when we were* 4_{T4} *discussing themes and other things, I had no clue what will be happening or what's going on".* Indeed, challenge to teachers' comfort zones was prevalent across all cases. Despite such challenge, the findings also revealed contradictions to teachers' aversion to play. The data presented many instances where collaborative attributes of the *formula maker, nervous perfectionist, resistor,* and *panicker*, essentially resulted in successful STEAM outcomes, demonstrating variables in the most desirable qualities of a growth mindset. Therefore, aversion to play in the research, can be broadly interpreted as fear. Such a powerful emotion emerged in the data in several forms, moulded into submission by curiosity, perseverance, and the encouragement of fearlessness, peer to peer. *"So I* 2_{T4} *was like scared… fear, discovery and enjoyment, I guess those would be my three describing words".*

4.5.6 Teachers' emergent curiosity for STEAM learning

Experience sampling (ESM) was used to capture teachers' emotional experiences in context, and was conducted predominantly in the 'making' sessions related to LF and BB projects. I was interested to see how teachers' curiosity was sustained while engaging in the mathematical concepts *and* the 'maths-making' integral to BB (4.2.2). While ESM was not conducted longitudinally, the quantitative data collected from teachers during BB PL provided results that support teachers' *erlebnis* experiences. The data addressed the research questions by examining how teachers 'viewing themselves' through the lens of affective behaviour might engender small or large transformations though emotions felt while making. The aim of ESM in the research was to identify the emotions felt by teachers in relation to challenging STEAM 'making' tasks. ESM was not conducted in non-'making' STEAM tasks. Figures 4.29 – 4.31 show aggregated teacher responses to ESM questions across three cases:

1. Before we start the Binary Bugs STEAM activity, which emotion do you feel right now?
2. How did you feel while making your Binary Bug?
3. How do you feel now that you've completed and lit the Binary Bug?

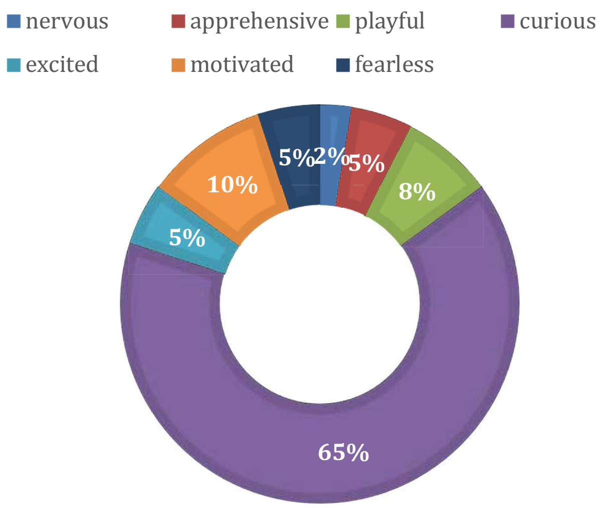


Figure 4.29: ESM question 1: Before BB. (n=44)

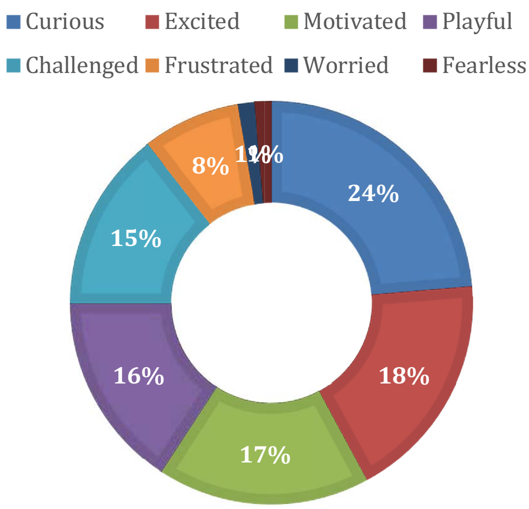


Figure 4.30: ESM question 2: During BB. (n=44)

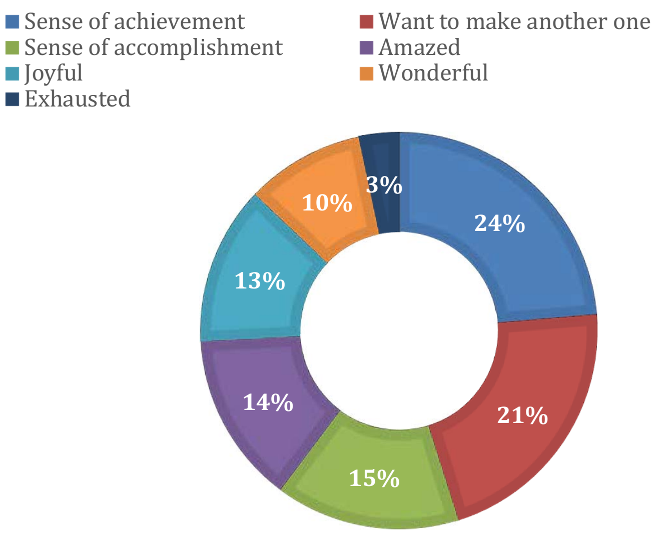


Figure 4.31: ESM question 3: After BB. (n=44)

Results from before and during the activity show teachers remained curious about the project while making the BB artefact (4.2.2). Twenty one percent of teachers expressed the desire to 'make another one' straight after the BB activity was completed. The data suggested that for some teachers, curiosity related to STEAM content *and* the physical activity was sustained. The variety of other emotions revealed through ESM were more indicative of small transformations, suggesting that the teachers' sense of accomplishment and achievement was gained not only through curiosity, but through perseverance.

Additional post-delivery surveys (n=26) conducted across STEAM 1, 2, and 3 after completion of broader STEAM PL (including BB), demonstrated 80 percent of teachers 'discovered some new ideas' or 'acquired plenty of new knowledge'. Teachers responded to the question: What did you gain from today's PL?. Twenty percent of participant teachers acknowledged new knowledge connections between maths and real-world contexts (see Figure 4.32). While the data set is small, the results suggested that curiosity was operative in teacher PL. However, teacher's curiosity in relation to perseverance appeared more importantly in data collected through qualitative methods; namely, observation and informal interviews. For example, in STEAM 3, teachers were curious to understand how STEAM would be received from the student perspective and how a student's conceptual understanding of STEAM would increase knowledge connections as well as satisfy curriculum requirements. STEAM 3 teachers were conscious of potential student (and parent) issues "*they* (students and parents) 3T2 *might not consider this to contain enough real maths or science*". The data demonstrated that PL sessions involving engaging with STEAM content via perseverance 3T1 in *making* as well as *making connections*, encouraged the teachers to conclude that BB did indeed, contain enough *proper* science or *real* maths.

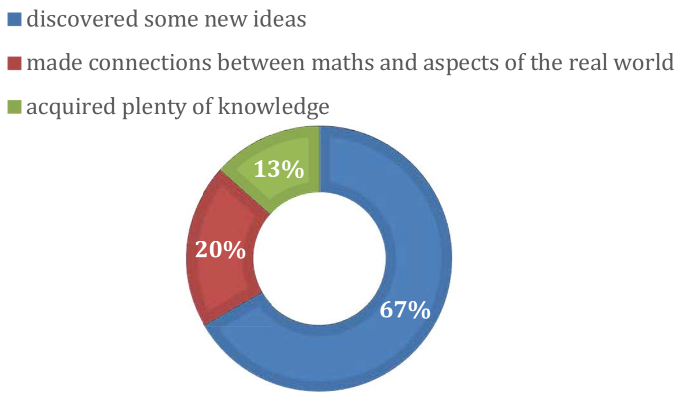


Figure 4.32: STEAM Post-delivery survey (n=26)

STEAM 3 teacher discourse during PL provided affirming evidence of how perseverance through curiosity led to exposure of knowledge/experience connections. Confirming the same, the Principal at School 1 revealed, *"This is the best PL my staff have ever done. It's* 1P *about them (teachers) owning their practice. Let's focus on the teachers driving their own learning, and then the learning of their students"*. The challenge for maintaining curiosity for STEAM teachers, therefore, is to remain motivated and persevering.

Comparing qualitative data related to teachers' curiosity across the cases over two years of STEAM PL and delivery to students, suggested a disparity between technological and physical components of the projects. For example, Teacher 6 commented about the use of AR technology in the STEAM PBL program in STEAM 1: 1T6 *"Bring it on! I've been wanting to learn this stuff for ages and now I get a chance to do something with it"* presented an excited curiosity about creating innovative pedagogy. Enter the *edupreneur*. The influence of perseverance on teacher curiosity was apparent over time in STEAM 1, leading to comments such as: *"This makes me willing to try some* 1T9 *more things even though I am the most technology illiterate person"*. Similarly, teachers in STEAM 1 self-identified a change in confidence, expressing:

1T7

> *"I'll be the person with my hand up because I'm like the – what you call – pre-digital dinosaur! So now, from last year to this year, you know, when they're [volunteer students] talking, I know what they're talking about – straight up. And it makes a difference you know. To my confidence, you know?".*

The former *nervous perfectionist* and *panicker* transformed. For some teachers however, curiosity pervaded all learning. Comments such as "*I think I was curious* 3T4 *throughout the entire time*", and "*I just want to know and do more of this stuff*" 2T1 demonstrated how certain teachers thrived on perseverance-led curiosity. Still, the data demonstrated how the influence of emotions on teacher transformation cannot be ignored during moments of peak curiosity during digital and physical STEAM learning.

4.5.7 The impact of emotions felt during STEAM learning

Interestingly, of the seven STEAM learning projects utilised in the study, the data showed that the four requiring extensive hands-on commitment to construct and complete a physical artefact; BB, LF, HP and FT (4.2.1 – 4.2.4) bore noteworthy emotional responses. Figures 4.28 – 4.30 indicate the range of activity emotions felt during BB PL. Similarly, outlaw emotions such as worry, fear and anxiety influenced the way teachers felt about themselves while engaged in STEAM:

2 T2 *"I'm crap at this"*
1 T7 *"I can't do it"*
3 T3 *"Get her to do it for you"*
1 T8 *"I was so scared at first"*
"I'm feeling really apprehensive"
4 T4 *"What's the point of this?"*

Curiosity manifested as 'wanting to know more' about paper transformation from 2D to 3D, which appealed to certain individuals, and frustrated others. The level of emotion experienced when folding the structures affected individual teacher's curiosity, evidenced through many comments along the lines of *"I love this project (and the [students] are going to love it too)",* and contradicted by comments such as *"I can't do this".* Using ESM in STEAM cases 1, 3 and 4, afforded teachers an understanding of potential pain-points their students might feel in the students' own STEAM making activities. Figure 4.3 supports the comments on STEAM process offered in STEAM 1, *"I was so scared at first and thought how am I going to do this? But I really got into it and learnt so much".* ESM data collected through STEAM making activities showed how tracking teacher emotions was a useful mechanism to measure 'pushing through' fear and anxiety related to learning by doing. Qualitative data also presented the range of emotional motivations related to discovering something new 'in-the-moment'. The impact of teachers' emotional contagion was observed through multiple 'aha' moments, ripe with playful curiosity: "*This is a unique way to visualise it. I found it hard but it was too interesting to give up. Relating biomimicry to probability to physical and functional qualities is coming back to some very simple mathematics*".

4.5.8 The importance of emotions in tacit forms of knowledge building

The presence of teacher emotions in the data collected across the STEAM cases points to STEAM learning being recognised as a channel for articulated *and* tacit forms of knowledge building. The so-called 'saboteur' from STEAM 2 was described regretfully by peers as "*Not being actively involved, that's sabotage. By wanting it to fall flat on its* 2T1 *face".* Such opinions were subjective; however, observation of the 'saboteur's' behaviour would confirm such concerns. Over time, however, the attitude and 2T2 motivations of the teacher appeared contradictory to the behaviour, revealed through formal interviews after the completion of the STEAM program at School 2. Teacher 2BT admitted his curiosity was driven by the urge to understand how the structure of the BB paper transformed from 2D to 3D: *"…the Flextale, I mean, how intelligent the person* 2T3 *who came up with this idea. I mean from little triangles, he thought of hexagonal, or he thought of this, and then ends up with this type of thing".* The tacit knowledge expressed by the teacher was replicated in additional interview responses post STEAM delivery, putting into question the label of saboteur by revealing a small but certain transformation. FT (4.2.4) activities were similarly confounding for teachers in STEAM 1: 1T3 *"…the hidden geometry tells the story. I don't get how it works but it does*". Regardless of the mystery related to the foundational geometry in Flextales, the data showed how teacher familiarity with the mechanics of the project gave way to tacit excitement: "*There's such a lovely kind of literacy aspect to it*", and also showed that teacher excitement was contagious: "*I think this would be a great tool to use in special education, or in textiles or any of the technology things where you need to demonstrate a sequence visually*". In Maths curricula: "*We could make it into an interdisciplinary project where in Maths they (students) actually construct it and know the geometry and how it actually goes… as well as the folding… but the story is created in another subject*".

4.5.9 A critical question: "Why are we doing this?"

The question emerged early in data collected from PL in STEAM 1, 2 and 3, as teachers were introduced to concepts and requirements specific to the implementation of STEAM at their school. The findings presented a certain level of teacher frustration and concern in these cases, mainly due to learning new digital skills, and lack of support or collaboration between peers to learn those skills. The data showed that in reference to FT in particular, the curiosity and perseverance exuded by participating teachers in

STEAM 2 was not matched by peers outside the STEAM program, specifically when participating teachers sought assistance with technological issues. "*They put this project*
2T1 *in the 'too hard' basket",* STEAM 2 lead teacher explained during post-delivery interviews. "*It was because we thought that they (students) had better skills and they didn't and that's an issue that I brought up with the senior executive … I said the kids have no ICT skills. They go 'what do you mean?'.* In STEAM 2, sustainability of STEAM FT was reliant on collaboration, namely, with teachers from Visual Arts and Technology (TAS). "*They [the students] have very little or limited digital technology skills. They didn't even know how to save things, how to email things, how to use Photoshop… but I thought they did it in TAS (Technology and Applied Studies), but they don't do it in TAS anymore".* The disappointment expressed by lead teachers in their efforts to collaborate with peers outside the program presented as an obstacle to sustainability of the program overall. The data presented this as representative of the *resistor* teacher type. It also emerged in the data that the same teachers were observed as unengaged, enthusiastic, hesitant and scared to participate in the Year 7 Numeracy day, the initial introduction to STEAM at School 1: "*I'm not doing that*"; "*Why are we doing this? It looks way too hard*". It is no surprise in the findings to acknowledge that the Year 7 STEAM program did not iterate into subsequent years.

Similar data emerged from STEAM 4, albeit related more to teacher frustration with conceptual learning rather than digital learning: *"I run PL for staff in secondary*
4T4 *maths and when I was introducing the Sierpinski triangle as a method of understanding aspects of mathematics, most of the staff were saying 'why?'. They kept asking 'why are we doing this?'".* The teacher expressed marked frustration with staff who could not see the point of making connections with wider STEAM concepts or the value of increasing technological skills, the idea was supported by teacher comments across the cases:
4T5 *"Maths is more than just numbers", "Making these connections is important for our*
3T1 *girls".* In the case of STEAM 3, teachers' expression of joy (an activity emotion) was twofold, first for achieving the BB STEAM task due to personal persistence, and second for encouraging the students to persist in the same challenge. BB (4.2.2) was described by teacher participants in terms of "*trying to do things by hand, without technology, is*
3PST *a good experience… getting them and us to use our hands".* This was new to the participating teachers from maths and science backgrounds. Likewise across the cases,

several teachers expressed the joy at experiencing professional development in which 1T4 they "*got to make something*". It emerged in the data that such experiences afforded teachers the opportunity to step outside perceived comfort zones and view their own capabilities differently, addressing both research questions underpinning the study.

4.5.10 Teacher transformation on the STEAM curiosity journey

Regarding Wagner's (2012) innovation attribute of curiosity, the data indicated that teachers participating in STEAM experienced a transformed relationship with the word 'why'. Juxtaposing emotions of anxiety *and* achievement were present in data across the cases, either through immediate feedback – ESM and group evaluations – or reflections – semi-structured and formal interviews. *"I had no clue what will be* 4T7 *happening or what's going on, not sure what this thing is. But when we started the three stages, probability things and so on, I started understanding things and I got more and more interested".* STEAM 4 data presented immediate feedback through group evaluations revealing teachers' STEAM discovery trajectory during the BB project:

> 4T3 *"It was interesting to see how many applications of maths we could do in the one activity. So you had the binary, plus you had the reflection/translation and that sort of thing. But it was a little bit frustrating with the folding, but I got a lot out of it because it's a fun activity, and then to see the end product. That was really good. Once you get over the frustrating bit, it's really good to see it all come together and see how the patterns are different. Actually I feel really* 4T7 *proud of myself".*

> 4T7 *"Though it is handsome (BB). It is very good because I understand the mathematical theory and those "reflection, translation" terms, yes. That content was meaningful for me. The theory".*

Paralleling STEAM 4, curiosity journeys were present in the data collected across each STEAM case. In STEAM 1, varying levels of positivity were observed as teachers wrangled with unfamiliar learning tasks: Teacher 8 learned block coding systems used in Lego Mindstorms™, Teacher 2 learned additional coding for use with Scratch and Makey Makey technologies, while Teachers 3, 4, 5, 4, and 7, developed new digital skills using Adobe Photoshop software and AR. All participating teachers in STEAM 1 were required to gain proficiency in online navigation, file management and digital processes related to creating interactive media. Additional teachers volunteering for the STEAM PBL immersion at School 1 were required to upskill in the same way in subsequent yearly iterations. Discovery, through teacher curiosity was collectively expressed by comments 1T5 such as "*We don't shy away from new challenges here",* and individually as: "*Once I* 1T8 *really got into it, I learnt so much. More than I expected*". Findings related to teacher curiosity presented the 'traits' once again: *neat freak, bull at a gate, nervous perfectionist, panicker, resistor*, and *edupreneur*. Collaborating in digital tasks and maths-making reinforced ownership of the creative contexts for the STEAM PBL program at School 1. Collaboration found the teachers reframing *why are we doing this?* as the collective notion of *what if we do it like this…?* Despite curiosity being a challenge for some teachers in the study, for example *"It was hard to know what was going on. I* 3T4 *couldn't do this, but I realised how important it was to keep trying, because the students would have to do it"*; such newfound edupreneurial traits reframed playfulness and curiosity as *enablers* of another activity emotion: fearlessness.

4.5.11 What if I can't do it?

Drawn from observations and formal/informal interview segments, the data revealed how critical connection existed between teacher fear and fearlessness in the study. Fearlessness was observed in the data through a range of layered expressions of teacher emotions. While fearlessness was a difficult entity to locate and record in terms of data collection, ESM data modestly acknowledged the existence of certain types of teacher *fear*, such as anxiety over potential failure, countered with joy in achievement. However, ESM could not quantify the action of *fearlessness*. Qualitative findings presented how teacher fearlessness emerged as nuanced spoken subtexts, layered beneath teacher comments recorded during structured or informal interviews. Frequent teacher comments related to fear of failure in the STEAM making tasks "*I won't' be able to do* 2T2 *that?*", or STEAM technology tasks: "*I'm not a computer person*", showed immediate 1T9 conventional personal responses to STEAM learning. The data exposed teacher fear in the sense of individual patterns of behaviour, frequently associated with performance 2T1 anxiety: "*What if I can't do it?"* It also emerged from the data that fear itself was the expression of teacher's resistance to change. "*Why change something that is working* 3T8 *reasonably well?".* Such sentiment presented as an individual characteristic. Fearlessness, alternatively, was presented as a collective trait, predominantly championed by bold leadership. Relating to phenomenography, the data presented confirmation of a temporal approach to releasing teacher fear in all cases, with STEAM

1 and 3 in particular, tracking teacher transformation from fear to fearlessness over two years.

4.5.12 Transforming teacher fear to fearlessness through STEAM

Analyses of the data revealed that teacher criticism related to STEAM frequently disguised teachers' actual fear of the challenges inherent in STEAM learning. The following table identifies different manifestations of teacher fears and the actions taken to allay those fears in relation to learning the STEAM content developed for this research. While Table 4.2 does not attempt to provide a definitive set of fear traits particular to humans experiencing challenging situations, it aims to represent the range of conventional concerns teachers might hold for transdisciplinary STEAM education, drawn from instances collected throughout this study. A large but essential table presenting data drawn from across the cases, describes the dissimilar circumstances regarding teachers' fear to fearlessness transition. For this reason, case examples range from teachers' apprehension to the use of technology, to the challenge of hand-making.

Table 4.2: From fear to fearlessness – teacher transformation.

FEAR ⟶ **FEARLESSNESS**

	CASE INSTANCE	CASE EVIDENCE AND ACTION	OUTCOME
EMOTION EXPRESSION	**Worry**	⟶	**Ease**
STEAM 4 teachers were worried about being unable to understand the maths directing them how to pattern and fold the Binary Bug.		4T2 *So I thought I'll just keep going, and keep going, and keep going and then I'll get it.*	The teachers' response to BB challenges was to persevere, indicating the transformative power of perseverance, or grit, in shifting from fear to fearlessness.
Data from STEAM 2 and 3 showed that making things with one's hands was the most challenging activity for the teachers. However, productive persistence, patience, practice and perseverance afforded the majority of the participating teachers new understandings of innovative methods of engaging with maths.		2T3 *We practice it before we show it to the students. We practice it, we do it ourselves, we go through it, and we practice it again.* 3PST *I went home before starting the project and watched all the videos set up by the head teacher, and even when I was preparing the bigger sheet for the vision-impaired student, I had extras, so I was folding and folding it at home, just to practice.*	*Before we started we're pretty confident, we're prepared.* The challenges of 'making' is consistently present in the findings and may be considered the greatest limitation to sustainability related to any of the STEAM programs in the research. Yet the desire to repeat the activities was also expressed, often immediately after completing the first attempt. *I just want to make more and more of these things.*

FEAR → **FEARLESSNESS**

	CASE INSTANCE	CASE EVIDENCE AND ACTION	OUTCOME
EMOTION EXPRESSION	**Complaining** →		**Engagement**
STEAM 3 and 4 teachers complained about how much time it took to 'get it' (referring to mathematical paper folding).		4 T7 *I found it hard but it was too interesting to give up.* 3 PST *The maths teacher needs to think outside the square to make the connections. That's the maths teacher I want to be.*	The data showed STEAM 4 teacher engagement with transdisciplinary concepts sparked interest beyond *sitting* and *listening.* However, STEAM 4 comprised of single session PL without provision of further evidence indicating how the teachers' integrated STEAM learning into STEAM practice STEAM 1, 2 and 3 programs were implemented immediately after nominated sessions of teacher PL. STEAM 1 and 3 programs are ongoing.
EMOTION EXPRESSION	**Concern** →		**Acknowledgement**
STEAM 2 teachers expressed concern related to the relevance of making connections between maths and the arts.		2 T3 *At the end of every project or activity, if you link it to what you really want to achieve, what you really want to know, then it fits* 2 T1 *I'm amazed and astonished at how many of them [students] remembered the name of that shape.*	STEAM 2 teachers acknowledged the powerful effect of STEAM learning on knowledge retention for themselves and students during and post STEAM delivery. The shape Ms.SV is referring to is the Hyperbolic Paraboloid. Both teachers and students were impressed with the applications of HPs in cross-curricular learning.

FEAR → **FEARLESSNESS**

CASE INSTANCE	CASE EVIDENCE AND ACTION	OUTCOME
EMOTION EXPRESSION **Incapability** →		**Proficiency**
In terms of embracing transdisciplinarity, teacher attitudes towards technology integration wavered between incomprehension and acceptance. This was largely due to a perceived lack of need to embrace technology at the time of the research field work for some of the participating teachers.	1T9 *I had a student with me to help me but she ended up taking over and I think I need to do it by myself to really feel like I know what I'm doing.* 3T1 *I wasn't sure about this project at first but now I see how it has real potential. So I'm thinking now, how do we scale this up? Make it bigger and better even.*	Teacher insights relating to their own capabilities were revealed over time in STEAM 1, 2, and 3. Although in STEAM 1, the learning trajectory was broadcast across the school, not unnoticed by the executive. 1P *For me the program provided a framework for like-minded group of teachers inspired by technology, a purpose and direction and permission to think differently and to be creative about their work*
EMOTION EXPRESSION **Obstinance** →		**Open-mindedness**
In STEAM 2, varying degrees of teacher obstinacy hampered parts of the STEAM program, parenthetically described by both lead teachers as 'sabotage'.	2T1 *What I meant by that was that they just didn't want to do anything, so by not doing anything it's sabotage.*	Over time, changes in teacher attitudes were observed, primarily as a result of the relationship built between peers and with students during STEAM delivery, described as: 2T1 *But then they came around. When they saw the kids hanging out for this one period a cycle was even something that's different. …so in that respect, they came around a bit.*

FEAR → **FEARLESSNESS**

CASE INSTANCE	CASE EVIDENCE AND ACTION	OUTCOME
EMOTION EXPRESSION **Obstruction** →		**Cooperation**
The data revealed teacher obstruction manifesting in different ways across the cases, generally associated with the teacher 'traits' and not due to the STEAM program overall. Teacher frustration with this type of peer behaviour was voiced during structured and informal interviews.	4 T4 *What's the point of 'not seeing the point'?* 3 T5 *Why didn't you just get her (the researcher) to do it?* 2 T2 *The others don't want to put in the effort. I think they're at a point in their lives where it's too much work*	Certain participating teachers were hesitant to work without assistance. Some needed concrete evidence of how the STEAM programs met learning outcomes, and others were not interested in collaborating. Despite that, small gains were evident in the data in relation to teacher acceptance of STEAM collaborative methods applied in the research: 2 T3 *Working together. It's kind of weird at first, because you've got to change up a little bit and shake it up, then I would be more than happy to do it.*
EMOTION EXPRESSION **Challenge** →		**Acknowledgement**
Challenge in STEAM learning was seen as dependent on peer enthusiasm and collaboration if fearless pedagogy was to be endorsed.	4 T6 *I don't think we would do this particular project with our kids but what it pointed out is that you can challenge yourself to design challenging projects, and that's ok*	The data showed that reframing teacher fear and insecurity related to participating in unfamiliar STEAM learning as *challenge*, found teachers acknowledging their ability to accept personal and professional challenges across learning contexts.

FEAR ⟶ **FEARLESSNESS**

<table>
<tr><td></td><td>CASE INSTANCE</td><td>CASE EVIDENCE AND ACTION</td><td>OUTCOME</td></tr>
<tr><td>EMOTION EXPRESSION</td><td colspan="3">Resistance ⟶ Support</td></tr>
<tr><td colspan="2">STEAM 1 data exposed a level of resentment or resistance to STEAM emanating from the behaviours of teachers outside the parameters of the STEAM PBL program. Such resistant behaviour impacted the experience for participating teachers, that is, the STEAM team teacher volunteers. The participating teachers put themselves forward for the STEAM program, with the view to collaborating and solving problems logically and strategically.</td><td>1P I’m in a unique position because I see that my biggest resistors are also my greatest allies

1DP I think that doing a project like ours allows teachers to collaborate with each other and learn about each other’s craft and take moments to say ‘wow I didn’t know that’s what they do in that subject or that’s the way they did things with students’. Because often in high schools we are so isolated from each other’s faculties.</td><td>STEAM 1 Principal flipped the context of teacher resistance to STEAM PL, proving to non-executive and executive peers that small pedagogical victories are made through collaboration and support. STEAM 1 Principal and Teacher 1 vehemently defended the STEAM program, disseminating its success across the school. In effect, external resistance was allayed due to the exposure of STEAM teachers’ fearless resilience. This, without trepidation and with many known unknowns.

Observational findings collated from all cases situated in school settings showed how the Principals’ fearless approach affected teacher engagement with STEAM learning, indicating how lack of initiative can be influenced and allayed by fearless leadership.</td></tr>
</table>

FEAR → **FEARLESSNESS**

CASE INSTANCE	CASE EVIDENCE AND ACTION	OUTCOME
EMOTION EXPRESSION **Confusion** →		**Clarity**
Observation and analytic memos from STEAM 1 presented a range of teacher silences and oppositional body language (crossed arms, minimal eye contact) during initial PL sessions. Such instances were interpreted as nuanced expressions of fear and anxiety caused mainly by what appeared to be teacher confusion, specifically in relation to the digital requirements of the STEAM program co-created for that school. It must be noted that teacher participants in STEAM 1 were new to digital platforms such as Google Classroom. Portentous silence in relation to apparent complexities inherent in digital file management found teacher anxiety in need of careful and empathetic management from the lead STEAM teacher.	1T1 1T5: *So are the kids making their PBL suitcase and putting it into the classroom folder, is that right?* (the PBL suitcase was a folder of digital items the students collected prior to the STEAM PBL immersion). 1T1: *They're not making their own classroom but Google Drive and Classroom, yes.* 1T6: *It'll turn up in the classroom but you do it through Google Drive.* 1T1: *That won't turn up in the Google Classroom app, not on that platform. Google Drive, then Classroom. So the difference is… when we go to this particular Google suite, where are we…* (1T1 navigates around her phone. Everyone else is silent. Someone chuckles.)	Data such as this sample from STEAM 1 revealed the interplay of fear and fearlessness was most prevalent in relationships developed between STEAM leaders and STEAM teachers. Empathy was consistently present in collegial banter between the executive and classroom teachers, resulting in easement of confusion as the program progressed. Collective patience and perseverance resulted in many gains for the teachers in terms of digital proficiency learnt through the STEAM program. This, combined with the evolution of clarity related to the 'making' tasks was a small, yet key component of the fear to fearlessness trajectory. 1P *Everyone has a different speed of learning, they do things differently, and they have different priorities. You just need to be understanding in whatever they put forward.*

FEAR ⟶ **FEARLESSNESS**

	1T1: *Now this one* (looks around at the silent team in the room*), ok… I'm losing people.* (Teachers laugh.) 1T1: *How much further should I go backwards?*	*Just applaud them, and encourage them, and celebrate it with them*
EMOTION EXPRESSION	**Indifference** ⟶	**Empathy**
Data from STEAM 1 and 2 indicated situations in which Year 7 students were exposed to the vulnerability of their teachers, in terms of how the teachers themselves were responding to physical *and* digital challenges built into the STEAM programs, increased the level of student-teacher rapport. Data across cases was indicative of teachers' understanding of STEAM experiences from the student perspective being similar to their own.	4T2 *You're going to be in the position of your students when they are faced with a challenging activity, when they might struggle to understand, or construct something – so by challenging yourself, you feel empathy.* 2T1 *It's creatively sticky learning – a different form of learning. It's making connections between different things. We are going to make sense of the mathematics in the first project, geometry and things like that, as we progress through the next project.*	Increased empathy was a positive outcome from the anxiety teachers felt while playing in the digital space or with conceptual mathematics. Short term effects, such as teachers' ability to use persona mapping to anticipate student 'pain-points' in STEAM learning, were conducive to increased confidence in the sustainability of STEAM inspired curriculum development. Increased student-teacher rapport had long term effects, demonstrated in the data from STEAM 2. 2T1 *Those kids are now in Year 9 and we have a completely different relationship with them, much closer, because of the STEAM program they did in Year 7*".

The aim of STEAM 1, 2 and 3 was for teacher autonomy and ownership of the STEAM programs. The data nonetheless presented obstacles to STEAM learning (outlined in Table 4.1), generally observed through teacher behaviour and interpreted through teacher interviews and group evaluation comments. Analysis of such showed that obstacles dissipated over time, and the so-called subversion recorded in teachers 'anti-STEAM' actions was dispelled as teachers' self-confidence grew.

4.5.13 You know what we could do now?

Data from STEAM cases 1, 2 and 3 demonstrated how meaningful relationships amongst teachers leading the STEAM programs, and those participating in the programs, were engineered to overcome obstacles. Each STEAM program provided situations where personal and professional transformation was offered as a natural by-product of engagement in fearless pedagogy.

2T1 *"I think that our staff respect us enough to know that what we ask them to do has meaning and even if they feel scared they still do it. Because we come up with some whacko ideas sometimes… and they don't know where it's heading but it always heads in the right direction".*

Comments such as this from STEAM 2 revealed how teachers' fear *and* fearlessness were powerful generative members of the same emotional family. When interviewed about STEAM motivations, STEAM 1 Principal expressed enthusiasm for innovative programs being developed at the school, in terms of collective appreciation and uptake from all staff: "*No more finger pointing or bias. Teachers can't just come in and behave like*
1P *complete foreigners. We have to be on board with this, and by that, I mean all of us*". Teacher participants across STEAM 1 and 3 cases in particular, sought additional creative learning challenges involving paper engineering and geometry. Top-up PL sessions were arranged, within which former instances of teacher resistance or fear were found to be absent. Observational data collected at subsequent PL sessions found increased excitement and enthusiasm associated with *learning something new*. The difference between PL sessions from each case was observed through participant observation and teacher interviews, where the maintenance of exuberant teacher attitudes towards balanced transdisciplinary STEAM was evidenced in varied configurations of "*you know*
3T1 *what we could do now…"*.

Observation of the activity emotions experienced by teachers through the focus area of play demonstrated how STEAM sustainability was supported by playful positivity and empathy. For some of the participating teachers, STEAM sustainability was fed by the desire to know more; to be curious. Findings related to both focus areas of play and curiosity addressed the encouragement and engagement aspects of the research questions across the cases.

1T3 *"I don't understand this but somehow it works".*

3T3 *"I'm going to make more and more of these!".*

2T1 *"I can't stop flexing this thing!"* (referring to a completed Flextale).

Findings from STEAM 1, 2 and 3, demonstrated how teachers delivering the STEAM 1P programs were required to *"get on board"* by trusting STEAM leadership as well as trusting the process of transdisciplinary learning. Analysis of the data finds that transdisciplinarity required collaboration above all else, and that for teachers to 'get on board' required a certain level of passion. The next section of this chapter presents findings related to teacher passion, considered in the same way as curiosity, through its relationship with actions of perseverance. Correspondingly, passion was found to motivate STEAM learning in the context of teachers wanting to know more, evidenced by teachers' desire for maintaining enhanced transdisciplinary pedagogy. Thus transforming 'what if I can't do it?' to 'what if we do it together?'.

4.5.14 Teacher passion and perseverance in STEAM learning

The relationship between teachers' passion for STEAM and a successful or meaningful outcome from STEAM learning was due to the action of perseverance. In the words of the Principal from School 1, *"The STEAM project has deeply connected teachers,* 1P *executive, students, parents and community through passion and conviction".* Such observations were interpreted as passion *after the fact*, offered through reflective evaluation. The data showed individual descriptions of STEAM learning expressed by participating teachers were verbal or embodied instances referring to new passion for STEAM pedagogy in the context of the teacher's sense of self-efficacy: *"I'm amazed that* 1T8 *I've actually done this. I could do it again tomorrow"; "I feel like the most accomplished* 4T1 *person in the world!".* If conviction can be interpreted as perseverance, teachers' passion for STEAM learning was also observed in the data as a method of increasing teacher collective efficacy, benefitting the collaborative group and potentially the entire school. *"I was told that we were mad to go on this journey the first year, and (the*

Principal) was also having a heart attack, saying, '[1T1], we can't pull this off, what do 1T1 *you want to do?' And I sort of said, I think we can. We can do this. We could put our school out there to be doing something amazing. And thanks to you guys, it's just been a rollercoaster".* The example expresses the teacher's appreciation for the collaborative perseverance shown by participating colleagues in STEAM 1, supporting previous comments related to passion and conviction from the same case. In comparison, data from STEAM 2, revealed the relationship between teacher passion and perseverance to be less collective: *"The others weren't really interested. They did it but it was us that* 2T1 *made the big commitment*". STEAM 2 required teachers to continue STEAM conceptual learning in regular Year 7 maths classes. For the two lead teachers, such commitment from their team was seen to be lacking. It is important to note that STEAM 1 PBL was an immersive program delivered over 6 – 8 consecutive school days, and STEAM 2 was delivered longitudinally, one lesson per fortnight over three terms. It emerged in the data that maintaining teachers' positive and affective levels of passion or enthusiasm for STEAM was dependent on the method of activation with students. Embedding STEAM concepts into regular classes relied on the passion and conviction of individual teachers at School 2 and 3. The data indicated such motivations were not forthcoming, 2T1 expressed through comments such as: *"and teaching for them is just … a job*", and: "*just* 2T2 *a job, not a profession. Not their passion*".

In response to the research questions, co-design of STEAM tasks was necessary for teachers to experience any degree of pedagogical transformation. That is, when teachers were stakeholders in the program and not simply 'conscripts'. By conscripts, I mean teachers who did not self-nominate to be part of the STEAM programs but were involved with STEAM due to professional responsibility at regular faculty levels. The data showed that igniting passion for STEAM for some teachers required proof of the fact that STEAM learning would 'work'. Teacher interview responses, when asked specifically about the level of interest in the current STEAM program or potentially developing STEAM projects of their own, were vague:

2T3

> *"Me personally, if I could see, if I could see where it's going, how it works and proof that it works, then if I had people coming that say 'oh I've tried this program, try this, it's great, it's excellent. Then I would do it".*

3T5 *"My hesitation was like, I've never done this before, so how do I know if it works?".*

3T6 *"And if it's just an idea, just one of many ideas we hear about, then I probably wouldn't do it, because I wouldn't know if I could do it… on my own".*

2T4 *"I'd be hesitant to work without um… assistance… a team. Direction. Someone to mentor me through it until I, like told me what I'm supposed to do until I learn how it, how it functions, if that makes sense".*

Data from structured interviews with teacher participants in STEAM 2 revealed the discrepancy between levels of teacher passion for STEAM did not go unnoticed. Teacher 2T1 1: "*Well I'll say… it's our passion, their loss. Honestly, it's their loss because if they can't see the relevance of what we are doing and why they need to make it relevant for their students, well then…".* By force of habit, Teacher 2 interjected *"…and what the kids get* 2T2 *out of it too. You see the difference in the kids when they make the connections. That's like the light bulb, you know".* Nevertheless, findings across cases demonstrated how perseverance was particularly encouraged in the STEAM PL maths-making activities due to the aesthetic appeal of the artefact being made; "*I got a lot out of it, especially when* 4T2 *you see the end product*", and *"I encourage as much as possible. It doesn't always work,* 2T1 *but I know they'll get something out of it if I keep encouraging*". Peer support was seen to alleviate teacher's terror of feeling outside one's comfort zone, interpreted by PST in STEAM 3 as; "*[Teacher 8] said the folding was difficult and that her folding didn't work* 3PST *out perfectly. So I was told to make sure I knew how to fold before teaching this. I think if more perseverance was applied, [she] might have 'got it*". The data exposed this to be true, as Teacher 8 went on to present the STEAM program results to her peers, members of a professional learning network external to School 3. Such a result demonstrates how 'grit' in STEAM learning could be personally and professionally transformative.

4.5.15 How 'grit' in STEAM alters a teacher's mindset

Observational data revealed how teachers' passion was actioned through 'grit', or perseverance, nurtured through various peer-to-peer relationships amongst participating teachers in the study; "*And you know, the good thing is that we feed off* 2T1 *one another*". Teacher grit provided small transformative moments for teachers experiencing frustration and irritation during PL maths-making session, often expressed within data collected through teacher group evaluations in STEAM 4: "*Once you've got*

4T1 *over the frustrating bit, it felt really good to see it all come together and see how the patterns are different*", and "*I just thought I'll just keep going, and keep going, and keep*
4T2 *going and then I'll get it*". Interestingly, data collected across cases revealed similar levels of teacher grit were evident regardless of the size of the STEAM learning program. However, the data showed the greatest impact of individual perseverance on the self-efficacy of the collective, was observed during STEAM 1 in regard to all of the activities ranging from paper engineering to digital troubleshooting. For example, in a post-delivery interview excerpt below, 1T1 speaks of her colleague in reference to STEAM 1 after two years of delivery at School 1. 1T4 was asked to facilitate the Flextales STEAM task for teaching peers as part of mandatory staff professional learning. 1T4 initially expressed apprehension because she was not considered the 'lead' teacher for the Flextale activity. During STEAM PBL immersions, 1T4 partnered with 1T3, a mathematics specialist, for the entirety of the program. At interview, 1T1 explained how she reminded 1T4 of her passion at that time:

1T1

> "*So that morning of the exhibition, [1T4] comes with printed schedule of what looks like the first day back [staff PL]. It was the first time ever … In the previous time, she's like 'I'm not doing it', and that was that. I said 'Mull over it, you know, let's have a think about it. And this time I said [1T4], I really think you could do this because we've just finished it. You've been in the room with [1T3} for a week, of course you can do it, you're an intelligent woman, who actually has been quite passionate about doing all of these STEAM things*".

Events transpired to see 1T4 indeed delivering Flextales PL to teachers external to the STEAM PBL program at School 1. Speaking of this teacher's pride, 1T1 continued*"…and*
1T1 *she is, she's so proud of her work, and that's really good value. Sometimes people have a misunderstanding, because she appears to be quite negative. I just laugh it off. You just laugh about it, because they're wrong. She's really committed… and persistent".* The *nervous panicker* demonstrated the transformative power of grit: "*I really wasn't sure if*
1T4 *I could do that, because I'm not the expert. But I pushed through. It was ok. Actually I think they [teacher peers] got a lot out of it".*

The emergence of teachers' perseverance or grit in the findings provided evidence of teachers' willingness to release the domination of perceived frontal based teaching conventions. The data showed such conventions to be replaced by more diverse and innovative methods of delivery, including collaboration. This was a challenge for some teachers: *"Before, I wanted to be left alone and work with my kids in my own* 1T3 *way, but now, I really see how it works, doing it together"*, and "*obviously we're not* 2T4 *going to do something for no reason but my hesitation is because I'm someone that's from not a strictly maths background… but if my head teacher said 'this is great', I have to do it.* Teacher trepidation communicated in the reflective interview data related to STEAM learning challenges, was contradictory to teachers' observed perseverence. Such contradiction afforded my interpreting the teachers' behaviour as grit. Teachers' commitment to sharing the STEAM learning and caring about what was being learnt was evident. School 1 Principal commented: "*I felt really, really proud, because it doesn't* 1P *matter whether they're seasoned teachers or not. It's that it's all new for us as well. The fact that they're taking one step forward, regardless how long it's taking, because everyone's a different learner*. The attribute of 'grit' emerged as evidence of shifting mindsets for teachers in all of the case studies. Grit provided an effective antidote to teacher self-efficacy questions such as "*How does it look… how do I look, teaching it?* 2T3 *How do I fit myself in?"*, and "*What if I can't do it?"*. Observation of the difference 1T4 between the PST's experience in STEAM 3 compared with the experience of the classroom teacher demonstrated how grit contributes to growth mindsets in teaching. 3PST *"You need to challenge kids these days and not give everything to them on a platter. I think [3T8] wanted me to do that for her* [the platter]. *But if you don't persevere … you're never going to achieve that success. If you persevere, you're not a failure".* Qualitative findings therefore showed how the troublesome nature of teachers' liminal states, regarding making changes to teaching practice, was potentially transformative.

4.5.16 The liminal in relation to teacher passion and STEAM learning

Qualitative data from STEAM 1, collected over two years of STEAM delivery presented solid examples of how liminality can influence teacher attitudes to 21st Century skill requirements, in particular, the skill of collaboration. Specifically, from the area of Mathematics teaching:

1T3

> *"Personally, for me, I would say, I never believed in group work. Sorry. But since I've done this (STEAM PBL), you see how one slacks and the other picks it up. So I've tried it a few times in my class now. But failed twice. Still I try to translate it into my classroom. I'd give it a thought now, group work, before… I wouldn't consider it at all".*

Considering the questions behind this research, 1T3's transformation provided evidence that teachers can explore other ways of viewing themselves through STEAM learning experiences. 1T3's description of the evolution of her personal STEAM learning from one year to the next, referenced collaboration with peers and student helpers (from higher year groups) who volunteered for the program: "*Yeah, last year I panicked, because if a* 1T3 [student helper] *was not there, I would panic. Oh my god, what the hell am I gonna do? But this year, I think if they're away, I can do it*". The transformation from *nervous panicker* to collaborator. The data revealed the uncertainty of teachers' liminal states on a smaller but relative scale in STEAM 4, to be equally transformative. Here, the *bull-at-a-gate* transforms also to collaborator:

4T1

> *"At the beginning when we were flipping and colouring, I felt ok. I felt I wanted to do it quickly though, to show I was confident but I wasn't sure that I had all of the information I needed. So there was a bit of urgency, but then I relaxed... but then the folding happened and I got a little bit stressed and puzzled again…"*

At this point in the group reflection, the neighbouring teacher interjects: "*then you* 4T2 *helped me".* Laughing, 4T1 continues: *"I felt really dumb because I didn't understand what was going on, and then I felt angry because I felt... this is like... this is not* 4T1 *happening, but now I feel like the most accomplished person in the world!".* Similar liminality was recorded across the cases: "*Can I just say that I've never done anything* 3T7 *like this before and I want to say thank you for making me see that I can*"; and "*This* 1PST *experience has changed my life*". In relation to the challenge of STEAM learning, expressions of teacher emotion evident in the data served as markers to teachers' liminal shifts, demonstrating how emotions experienced during engagement in STEAM activities enhanced teachers' professional and personal identity.

4.5.17 Growing passion for STEAM learning

A recurrent theme in the data was a sense amongst teachers that they had 'discovered something new' through participating in STEAM activities co-created for this research (see Figure 4.31). These views surfaced mainly in relation to teachers' passion for discovery through new experiences replete with empathy, collaboration, negotiation and appreciation of inputs from diverse perspectives. *"I believe trying new approaches* 3T1 *to get things done equals innovation and invention".* Passion for maintaining STEAM connected curricula was evident in STEAM 3 post-delivery, where two of the participating teachers (the *perfectionist* and *resister*) volunteered to share their learning with an external professional network (see Figure 4.23). Observing the former resistant teacher’s shift in mindset demonstrated how passion for STEAM was encouraged by admitting the power of failure: *“I couldn’t do this, but I realised how important it was to* 3T8 *keep trying, because the students would have to do it”.* The comment positioned the teacher’s actions firmly in the realm of empathy, anticipating the student experience, and as such, personified personal grit. The data showed how grit and passion for success became the *pivot* in STEAM PL, reframing failure into feedback.

Cross-referencing data from STEAM 3 to experiences observed in other cases demonstrated how passion, grit, perseverance and fearlessness were necessary for teachers to accept the challenge of disrupting entrenched and traditional modes of practice. In summary, 1T1, expressed after consecutive years of STEAM 1 PBL delivery: *“We're just getting stronger and stronger”.* Evidence of STEAM success for teachers in 1T1 STEAM 1 was also supported by data collected from volunteer PST participants from two tertiary institutions. Repeated comments declared over two years of delivery, was that “*We haven’t seen anything like this at other schools*”; or “*we are extremely grateful to* 1PST *the teachers at School 1 for providing such a unique opportunity to see cross-curricular teaching in action*”; and “*The program was in-depth and engaging and allowed students to explain the processes and skills they had been learning to us. We also saw teacher problem-solving and the design of appropriate solutions to any issues that arose”.* Sharing PST responses with the participating teachers at School 1 acknowledged their fearlessness in the face not knowing how STEAM PBL would be realised, and endorsed the distinctively creative approach to learning and teaching adopted by the STEAM teacher team.

4.5.18 Sensing teacher transformation through STEAM learning

While STEAM did not continue into subsequent years at School 2, and data collection did not extend beyond the PL sessions in STEAM 4, the findings revealed how astonishment and amazement related to a variety of the learning co-created for this research, was affective in large and small ways for all participating teachers. A sense of transformation existed both in terms of how teachers viewed themselves, and how students came to view them. This section of the chapter presents a range of instances from the data in which the teacher ‘traits’ were operationally transformative. The following table provides a concluding analysis of the traits aligned with summarised examples of teacher transformation.

Table 4.3: Teacher transformation through STEAM engagement

<table>
<tr><th>TEACHER TYPE</th><th>CASE INSTANCE</th><th>EVIDENCE OF TRANSFORMATION</th></tr>
<tr><td>the neat freak (NF) – exhibiting the desire to complete the activities without making mistakes or deviating from the guidelines.</td><td>NF emerged throughout cases 2, 3 and 4, in relation to Binary Bugs STEAM PL where a binary pattern was applied to the surface of paper templates according to a given set of probability rules.</td><td>Teachers released the belief that the pattern must be perfect. The idea of imperfection or ‘mistake’ was an emotional acceptance for teachers, shifting their controlled experience of the activity into an empathetic perspective of what a student might experience doing the same activity.</td></tr>
<tr><td colspan="2">4T2 “I’m so scared. I don’t want to mess this up”.</td><td>2T2 “You just have to dive in and don’t worry if you make a mistake.”</td></tr>
<tr><td>the formula maker – one who needs to plan and sketch before application, applying all the rules step by step with the aim of working out ways to make the process seamless for the students.</td><td>Emerged in STEAM 1 and 2 where teachers were nervous about preparation of materials and image manipulation tasks related to Flextales (see 4.2.4)</td><td>Teachers were motivated to ponder the hidden geometry inherent in the Flextales shape. Discussion with senior mathematics students led to the creation of a small website dedicated to investigating the maths inside the activity. It was agreed that the complexity of the mathematics was beyond any teacher’s knowledge, however the mystery of the mathematics is what makes the project so unique.</td></tr>
<tr><td colspan="2">1T3 “I don’t understand how this thing works, and they don’t either, so how’re we gonna get the kids to understand it without a set of rules?”.</td><td>1T3 “I still don’t get this, but somehow it works and it’s ok that I don’t get how it works”.</td></tr>
</table>

Table 4.3: Teacher transformation through STEAM engagement

TEACHER TYPE	CASE INSTANCE	EVIDENCE OF TRANSFORMATION
the nervous perfectionist – one who wants to get it right, can't stand mistakes, is usually silent and doesn't want to ask questions in front of the group	Represented notably in STEAM 3, where teachers were required to deliver BB project to students after limited PL sessions. Teachers in STEAM 3 were conscripted into the STEAM program, and there was no option but to 'get on board'.	PST in STEAM 3 was assigned to a specific class to assist the nervous teacher, when in fact, the teacher in question never 'got it' yet was enthusiastic enough to present the BB project to her peers in a mathematical professional network, revealing a transformed attitude towards effort in STEAM making, and a reframed response to failure.
3T8 *"I really didn't want to do this. Everything about it sits way outside my comfort zone".*		3T8 *"When I first tried this, I couldn't do it. You've gotta be patient … don't turn your back on it"*
the panicker – hysterics to start, panicking about everything but then coming up with well-constructed, thorough resources and solutions perfectly aligned with the needs of the students	STEAM 1 found a measure of panic in certain teachers, considered to be 'panic' by peers in the STEAM teacher, expressed by the lead teacher as hysterics.	STEAM 1 saw teachers learn a myriad of new skills in technology as well as experience challenging conceptual learning in STEAM making tasks. 1T8 expressed her experience vehemently from the perspective of initial disbelief. 1T8 evolved from a career of effectively teaching cooking and sewing, to a teacher of robotics and autonomous systems.
1T1 *"There's all that hysterics to start with, in the full knowledge that she will turn around and deliver perfectly well".*		1T8 *"My learning curve was like this!"[arms up in the air]. "I never thought I could do this type of thing"*
1T8 *"Oh god, I though what have I got myself into? This is never going to work. It's just too much".*		

Table 4.3: Teacher transformation through STEAM engagement

TEACHER TYPE	CASE INSTANCE	EVIDENCE OF TRANSFORMATION
the resister – one who will never come on board, who will potentially never ‘buy in’ who actively opposes involvement. Behaving ambiguously	Pockets of resistance were documented in the data collected across the cases. STEAM 1 presented a teacher example which was confusing and troubling due to the teacher’s perceived ambiguous behaviour and ambivalence towards the STEAM content.	Teacher 3 from STEAM 1 invited her entire family to the exhibition at the end of the first iteration of the STEAM PBL program. When asked why during post-delivery interviews, the response was in direct contrast to the perceived behaviour: 1T3 *“This stuff is so interesting to me and unusual. I wanted my family to see what I’ve been talking about all this time.”*
1T1 *“So I ask what’s the problem? We need to actually get our teachers to see the problem and then they need to problem-solve without it being almost like a chore – but don’t worry, she always looks like that.”*		1T1 *“What I love about her is that she does go and explore even more to make it even more attractive and make it even more exciting. She owns it. Her owning that project was phenomenal to see. She has so many different responsibilities and yet still made the time to do extra research and find out exciting new things.”*
the saboteur – places obstacles in the path of achievement, theirs and students’, ultimately considering the activity to be of little or no value to teaching and learning	STEAM 2 presented a confounding situation related to teacher’s sabotaging the program. The teacher in question was observed as obstructing students’ flow of understanding even after completing PL successfully.	STEAM 2 teachers were ultimately guided through the STEAM learning alongside the students, with lead teachers taking over the necessary direct instruction. However, interview comments revealed comments contrary to sabotaging behaviour during STEAM delivery.
2T1 *“He’s telling them all the wrong things even though he knows it’s wrong. It’s sabotage.*		2T3 *“I don’t want to forget about how you can use Maths to make things wonderful and really entertaining to people.”*

Table 4.3: Teacher transformation through STEAM engagement

TEACHER TYPE	CASE INSTANCE	EVIDENCE OF TRANSFORMATION
the edupreneur – excited co-creators, exhibiting all the hall-marks of the innovator: willing to play, and are openly curious, visibly passionate, and fearless in the face of resistance. These teachers are committed to a collective purpose	The lead teachers participating in this research were observed as already operating as edupreneurs. The behaviour of these teachers demonstrated distinct motivation for fearless and forward thinking pedagogy, aligned with current state and national STEM education strategies. Select individual teachers contributing to the STEAM teams demonstrated the same drive and welcomed the opportunity to test the edupreneurial waters. The example here is from STEAM 1.	Relating to interview comments expressed by 1T6 on completion of the first STEAM PBL student immersion in STEAM 1, what seems like a small, personal response, represented transformation towards team-driven cross curricular connections in STEAM learning. *I am very excited to continue to learn* – enthusiasm and motivation. *I am very excited to continue to grow* – curiosity for personal and professional development. *I am very excited to continue to push boundaries* – fearless words of a teacher willing to take pedagogical risks. *The passion comes from*… a collaborative, connected field of view. It is important to note that PDHPE teacher 6, pursued further STEAM opportunities, securing her own position as head STEAM teacher at another school within six months of the first STEAM PBL delivery at School 1.
1T6 *"I am very excited to continue to learn, grow and push boundaries. The passion comes from working with people like you".*		1T6 *"I look in the mirror now, and I don't recognise the old me. I see that new person – STEAM leader, Innovation expert – and I say to myself "who are you" and "how did I get here"… but here I am. It's great! Bring on professional development and teaching growth!".*

Conclusively, the presence of activity emotions in STEAM PL exposed how STEAM collaborations required teachers to acknowledge renewed collective purpose. Findings related to purpose are presented as 'Intellectual Commitment'. These are explored in the next section of this chapter.

4.6 Intellectual Commitment to STEAM

Turning now to 'purpose', the fifth of Wagner's (2012) innovation attributes, a common view amongst interviewees was that the STEAM learning enacted through the study highlighted the value of teachers' collective experience. In this part of the chapter, data related to the experimental and experiential approach particular to the unique STEAM PL underpinning the research, presents as teachers' *intellectual commitment* to STEAM. Intellectual commitment refers to the intention, or purpose, of enacting the STEAM pedagogy co-created for the study. Purpose links the preceding focus areas of play, curiosity, passion and fearlessness, by documenting how experimental and experiential threads in STEAM learning were connected within each of the case studies. Section 4.3 and 4.4 focused on *erlebnis* (unmediated in-the-moment experience). Section 4.4 positions *erfahrung*, the German word interpreted by Dewey (1938) as the 'reflective and cumulative experience', equally valuable to STEAM learning. The following data present extrinsic evidence of *erfahrung* through teacher acknowledgement of STEAM's pedagogical orientation in national STEM and innovation policy. For example, IN STEAM 1, robotics technology was introduced to participant teachers on the first day of STEAM PL, resulting a sense of panic. This emotion surfaced mainly in relation to the question:
1T7 "*Why are we doing this?.* The response from lead teacher 1T1, with support from the school's executive was in defence of the school's curriculum innovation initiatives:
1T1 *"Because our school has invested in 12 Lego Mindstorms kits and now we have to make them fit".* 1T7 asked: *"Why did we do that?",* to which 1T1 pointed at me (the researcher), saying, *"She told us it would be a good idea*". The most striking result from this research instance was the ensuing collaboration amongst teachers, in which they simply had to find a way to make robotics fit the STEAM PBL program. *Nervous panickers* transformed into *eduprenuers*. Analytic memos at this time show the nature of erfahrung evident in teacher reflections of serendipitous creative and imaginative STEAM experiences. Figure 4.33 depicts STEAM 1 teachers constructing the robots using

Lego Mindstorms kits in preparation for use in programming for the STEAM City project at School 1.

Figure 4.33: STEAM 1 teachers collaborating in robotics

4.6.1 *The value of experimental STEAM in teacher professional learning*

One of the research questions asks: How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves? A variety of perspectives presented in the data related to this question in terms of teachers' sense of purpose through experimenting in STEAM learning. Commenting on experimental learning and the importance of "*getting outside your comfort zone*", 4T3 teachers across the cases consistently positioned themselves in the same learning framework as their students, such as:

> 1T6 *"It's a different form of learning. It's making connections between different things. We are going to make sense of the mathematics in the first project, geometry and things like that. Showing that link for her will calm her down a bit".*

> 1P *"New terms [design thinking, STEAM, hybrid, transdisciplinary] currently scare them [teachers} so we need to make them part of all our practice"*

> 3T1 *"For them [teachers] to see the power of doing and making and then seeing where it could be used in their subject area? Even just one component".*

Comments on experimental learning chiefly presented in the data as working towards a collective STEAM learning goal, expressed as: "*silos are still there but we need to cater* 1T1 *differently to our clients (students)", and "particularly the bottom kids. Moving away from that textbook type teaching and you know, making it relevant to the kids, that's* 2T1 *the most important thing*". While the action of experimenting or playing around with ideas in STEAM affected individual mood and erlebnis, the findings demonstrated that the mood of the group, the collective, and establishment of collaborative purpose, was the greatest influence on environmental atmospheres affecting teachers' view of themselves. From STEAM 1:

> 1T1 *"To actually have our non-experienced ladies, you know who some of them don't even strike you to be experts in this subject area or masters of their craft, get together as a team. And I think in the first year that we have established that we've got each other's back and that we could achieve this something, this amazing thing. I just don't think it could get any bigger than this".*

This comment embodies erfahrung, the 'reflective and cumulative experience', and shows how purpose emerged through expressions of teachers' connected aims and shared understandings in STEAM learning, a common thread running throughout the research. Teachers' collective purpose was identified in comparison with individual purpose, emergent in the data as atmospheres of not knowing and then knowing. The value of STEAM experimentation was defended in STEAM 2: "*It makes so much more*
2T2 *sense to them when they see the relevance 'and where am I going to use this miss?' and then you discuss how and where, you know, it just makes sense*". Similar sentiments
1T4 were expressed in STEAM 1 over the possibilities of using new STEAM skills in contexts
1T6 outside of the research: "*I want to include civics and citizenship aspects as well as*
1P *Indigenous*", supported by the STEAM 1 Principal: "*Getting the local council on board. This is a recognised area of apathy in learning – engaging kids in politics – democracy and so on … this could be a really great way to start them off*".

In contrast to teachers' perceived enjoyment presented in the data, experimental STEAM experiences drew a range of subjective reflections from certain participating teachers that represent positive *and* negative experiences: *"personally at*
2T4 *the beginning I was a bit scared. Scared, yeah, because I'm not, I don't have a Maths background so I was just looking and you guys were talking about it and obviously there was some prior discussion before I heard about it and it sounded like overwhelming. So overwhelming*". 'Overwhelmingness' was widely observed through initial teacher anxiety related to STEAM learning, however, frequently assuaged by teacher perseverance:

> *"Once I'd gotten into it I found myself enjoying the process as much as the kids were. I just kind of picked up with them because their need to know how to do something drove my need to be able to explain certain things. And it wasn't, once I looked into it, it wasn't that complicated. But showing them, it was like a discovery. So a personal discovery,*

> *which led to obviously, enjoyment of the whole process. So it was like a scared… fear, discovery and enjoyment process".*

The data showed similar experiential outcomes across cases: *"I was always wondering,* 1T4 *'how is this going to relate to the next activity?' But at the end we could see the relationship between all the activities. [Students] could too, so that was good;* and *"It's* 4T4 *called a glide reflection because it's two translations on the number plane. If you use this as a vehicle to explore probability, it's is really good. There's a sequence in this activity that makes many connections"*. Being "*excited to visualise these concepts"* was common to participating teachers, and specific to BB, the maths teachers "*all get a unique visual* 3T2 *representation of a random probability task*", leading to "*I think the kids were always* 1T5 *engaged and curious about what they were doing and so were we".* Erfahrung data presented evidence of teacher purpose through experimental PL experiences and in STEAM 1, 2 and 3, the subsequent delivery to students. There were observable correlations between teachers' willingness to experiment in STEAM and teachers' development into potential STEAM change agents at their schools.

4.6.2 Developing teacher agency through collaborative STEAM learning

A clear benefit of STEAM learning was the manner in which the learning contributed to shifts in teachers sense of agency and self-identity. Findings showed how the collegial 1T3 environment within which STEAM learning took place inevitably added to the way teacher agency evolved. Teachers' intellectual commitment to STEAM was defined as integrating Arts practice with STEM theory, with a view to enacting unique and valuable transdisciplinary pedagogy. Qualitative interview comments expressed intellectual contagion was extensive in collaborative learning, and evidence of increased collective teacher agency was presented through comments such as "*It is really important to share* 1T1 *and keep on reminding everyone that* ***we have done it TOGETHER****".* Teacher purpose, observed through the STEAM lens applied in this study, was a united driving force for increasing teacher agency. Teacher participants articulated the cumulative growth of collective teacher agency as:

> *"I'm not much of a collaborator. I didn't see the value of it before. I've learnt a lot. I didn't expect that to happen";*

and individual teacher agency:

> 2T3 *"So you can reflect and wrap the whole thing all together. So if you are doing this activity for Maths, you can finalise your whole activity by*

mentioning Maths, if you are doing it in Art, you can finalise with something with Art. You see, thing like that, you can wrap and get the whole picture together";

and intellectual teacher agency*:*

3T7 *"I agree that lifelong learning must include challenges in order to strengthen experience and increase knowledge".*

The findings showed how intellectual and emotional contagion flourished in teacher experiences during STEAM 1, due to the size and dynamism of the Year 7 STEAM PLB immersion program. *"I was excited about all the things were going to do together. I* 1T6 *thought it was too much to achieve in one week but we did it and I think we could do it again easily".* Again, contagion flourished: *"It definitely felt like we were working* 1T2 *together… gradually. The growth as a team when we faced challenges was great".* The following interview excerpt exemplifies how collaboration and connectedness emerged as key themes in the data, simultaneously recognising the challenge facing teachers in their attempts to connect the STEAM content.

1DP *"Often in high schools we are so isolated from each other's faculties. The more kids get exposure to collaboration happening, the deeper their learning goes. So they have to be able to connect the maths that they're doing in science with the maths they're doing in maths, and to start these partnerships happening with people".*

Here, School 1 Deputy Principal (DP) commends the balanced transdisciplinary efforts made by the STEAM team teachers. Correlating with STEAM 1, teacher participants across the cases reported shifts in their personal sense of self, illustrated by frank and honest comments in the data related to self-efficacy, value and agency. Some felt that 1T1 "*It's ok to do something hard. For teachers as well as students*", while others considered 3T1 "*We took a bit risk with this project and we had to just trust the team. These support structures are important and it's time to acknowledge that we can't just continue to* 2T1 *operate in the same way as we have always done. On our own with the doors closed*". Teacher uncertainty was identified, named (anxiety, fear, resistance) and reframed as fearless collective problem solving. Evaluating the STEAM program after two years of delivery in STEAM 1, lead teacher 1T1 expressed:

1T1 *"I think it is deadly big enough and to achieve that, you know, in a week and to have that exhibited in that timeframe, has been just phenomenal. I'm ever so grateful, I don't know how we did it. You know, just with that drive to actually, to keep playing in the*

> *partnerships. There is no way, I don't think we could be here at the second year at the stage without that.*

For a small number of participants, STEAM provided a force for change, enough to participate in iterative programming for STEAM 1 and 3. The data demonstrated that most teachers across the cases considered collaboration as the fundamental contributor to effective acceptance of STEAM challenges, expressed in STEAM 4 as becoming "*a little* 4T1 *bit stressed and puzzled… then with assistance from my two experts… collaboration was great. I think that's a key*". Collaboration served teacher agency well in STEAM 4: "*We* 4T2 *couldn't have done it without each other. Yes, that's the key in problem solving, sometimes*", and not as well in STEAM 2, where in the face of perceived enthusiasm for STEAM learning, the program did not run again at the school. In order to assess the reasons why, and in relation to the research questions, the data showed small transformative moments befell teachers in STEAM 2, yet the problem with STEAM sustainability was regrettably a ubiquitous problem for many schools: "*High school* 2T1 *teachers, I guess, we have our challenges in terms of being able to at least plan together. Being able to at least deliver it together and then be able to debrief together. Debriefing is incredibly important and powerful. That takes time and everyone is time-poor*". In contrast to this comment, at the end of the first year's delivery of STEAM to students, so-called time-poor teachers in STEAM 1, where the co-created program involved teachers from varied disciplines, immediately agreed to run the program again the following year. This is a striking result to emerge from the data, as STEAM 1 was expressed as intensely time consuming and often confusing. The most surprising aspect of the data however was the way teachers' behaviour across the cases was notably self-effacing, even in the face of encouragement:

1T1

> *"You need to take the compliment. She starts to get all, No. I don't want to hear it. You need to just take it in, 'cos you really were phenomenal. Your work was just outstanding. Then she sort of took a step back and thought about it and said, "Well thank you." That sort of thing and I said, "Yeah, we need to just celebrate what we have achieved." Anyway. She sort of said, I am convinced that you and I are very different thinkers. I said, "Well, okay, keep going." She goes you know, I can't handle once I've drawn a picture in my head any spanner in the works. I just have a meltdown and she acknowledged it. I didn't want to push or need to push it any further. And she said, "I have a meltdown." You are so fluid, people say something to you and you don't*

lose it. You just go with the flow. We are just very different people and I said, "we just certainly are and that is why we make a great team".

The interview comment above demonstrated how the *formula maker* and *edupreneur*
navigated collaboration in the learning at STEAM 1. Proving, as the Principal says, that
1P teachers cannot continue to "*behave like complete foreigners*". The majority of
participants were observed as positively constructing shared understandings of how
STEAM pedagogy not only served transdisciplinary curriculum development, but
established important efficacious links between teacher identity and agency.

4.6.3 Nurturing the Growth Mindset

The findings presented evidence of individual shifts in personal and professional identity
1T8 in responses such as "*I've learnt so much! I never thought I could do this type of thing*".
What was more surprising was the peer evaluation related to growth mindsets emerging
from the data. From STEAM 1 again: *"She's just really come out of her shell, she really*
1T1 *took it on board. She loves Flextales, so passionate about it, and she was so invested in*
finding out how it was done"; and "At the start, I felt very nervous and... as the growth
4T6 *mindset kicked in, we got going and I started to feel very engaged and feeling joy at the*
end, just feeling happy. I created something". Such comments provided evidence of the
presence of emotions being contributory to a teacher's sense of purpose in STEAM
learning. A particularly insightful example of personal shift was expressed by 1T4 after
the first public exhibition in STEAM 1: "*This is the first time I've wanted to show my*
1T4 *family what I do… what I've been talking about all these weeks*". And from STEAM 3 "*I*
3T4 *feel like I'm a member of a special club*". In contrast to the range of emotions
contributing to the growth mindset, teacher trepidation, anxiety and reluctance were
also present in the data.

Data related to the possible negative effects of STEAM, revealed how much of
the commentary related to individual teacher traits and vulnerabilities. For example "*I'd*
2T3 *be hesitant to work in STEAM without um… assistance like… a team. Direction:* and *"If I*
4T2 *don't know what I'm doing then how are they going to know what they are doing?".* In
2T4 the case of STEAM 4, teacher agency was openly questioned by certain participants,
expressing how "*It felt like we should already know these things but we don't*". Other
comments were related to the sense of certainty in teaching practice: "*I don't have time*
2ET *for things that don't work*". Also: "*It bothers me when I feel out of my depth in front of*

the class when I'm doing something like this". One comment from STEAM 3, "*It would* 3T6 *be better if I knew what was going on and where this is headed*", while expressing frustration, was indicative of the potential value of STEAM PL if positioned with ongoing collegial support. Collegiality, evident in the data through observation and interview comments, showed how careful collaboration and effective communication were essential to expanding or inhibiting teacher agency in all STEAM cases. Conversations related to future STEAM goal setting were motivated by high possibility stimuli, directly linked to professional learning, for example, "*Okay, if I'm the project leader, I need to* 1T1 *mould myself to actually embrace everyone's difference. Because if I don't do it, then we are only going to have war on our hands. I'm thinking 'okay, talk to me. what's making you nervous?".*

A bi-product of the STEAM 1 PBL program was the school's inclusion more than one prestigious education innovation conferences. Commenting on their inclusion. a 1T1 range of teacher emotions were expressed: *"And even today, I think our work was the* 1T9 *most popular. People kept on coming up and asking us about it. The kids were amazing. I was so proud*". The majority of teacher participants had not experienced exhibiting their work in external context, elucidating emotions related to the public event held on completion of STEAM 1 at the local retail centre: *"I just want to thank you for making* 1T8 *me do this. I haven't learnt so much in ages. I didn't think it would be like this at the* 1T9 *beginning. I feel very emotional right now*"; "*It makes me want to cry".* Evaluating novel experiences such as these found that teachers participating in a range of exhibitions on completion of the STEAM programs, presented substantial exponents of the growth 1T9 mindset: "*Oh... I feel exhilarated! And you definitely want to show it off"*; and *"I didn't* 2T1 *think I'd feel this emotional about what we've done".*

Transformative personal experiences were also observed as paramount to increasing teacher agency. The pursuit of newness in the face of adversity endorsed the attribute of *purpose* being fundamental to this section of the chapter. PL sessions related to learning robotics technology in STEAM 1 at School 1 provided much evidence of how collective purpose served as enlightening for teachers in terms of finding solutions for pedagogical problems. "*That's the one activity that was heavily questioned* 1T1 *in the first sessions – why are we doing robotics? How do we make it fit with our guiding question?".* Collaborative input to the question of how to include robotics technology in the STEAM PBL guiding question of “How do we better connect with our community?” demonstrated how lateral thinking was enhanced by teacher relationships, resulting in the development of ‘STEAM City’ (see Figure 4.8) . Here, purpose played its part in the study through creative collaboration, perseverance and empathy, drawing forth the 1T1 comment: *“Oh yeah, you’ve got to have your eye on the prize. You’ve got to make that happen”.*

There was some suggestion in the data that the prize for teachers in STEAM 2 was less audacious, particularly when faced with necessary curriculum obligations: “*The* 2T3 *confusion I felt at the start was because I couldn’t see where it all fits in with curriculum.* 1T2 *These questions, they were there the whole time*”. The question was, how should teachers find connections between their own STEAM learning *and* content in the curriculum. Data collected in STEAM 3 provided insight to such a problem. The STEAM 3 program culminated in exhibited work being open to the public, and teachers were visibly moved by the success of their achievements. “*We had over 170 bugs in the display* 3T1 *and they were all different because of the binary and probability we did. They weren’t the most eye-catching things in the show but they showed how you can learn these concepts both individually and in groups”.* In terms of how the teachers tapped into a renewed growth mindset, many expressed such transformation openly: *“This makes me* 1T9 *willing to try some more things. Now I know the level of technology that I can actually achieve*”; and frequently surprisingly: “*Yeah but the maths, I want to be able to explore* 2T3 *the maths. I could explain to my children, my own children, you know, they’re this sort of triangle and we place the images on them in this way and it turns like this but I couldn’t say why before. And now I want to know, and I do know”.* Interestingly, the latter transformative comment was expressed by ‘*the saboteur*’. The data showed how transformed teacher agency through STEAM learning, therefore, is subjective, incidental, serendipitous and sometimes unexpected. In terms of transdisciplinary pedagogy and professional shifts, the majority of teachers remained steadfast in their appreciation of each project’s transdisciplinary potential, for example “*When we saw* 2T1 *the Flextales, we saw it had a story behind it”;* and *“I thought, we should do this. It is a really good way of bringing the disciplines together”.* The findings presented that collectively, teacher experiences in STEAM learning demonstrated how shifts in teacher agency aligned with education policy more broadly. Qualitative evidence supporting such alignment is discussed in the next chapter.

4.6.4 Connections between STEAM and teacher professional kudos

Turning now to the qualitative evidence supporting the critical question introduced in section 4.4.9 – *Why are we doing this?* The result of participating in the research for teachers was observed to be mainly in the realm of professional kudos. As such, kudos was a key motivation for the teachers to continue cross-curriculum mapping through STEAM programming into the future. In the case of STEAM 3, teachers presented their Year 8 STEAM program to professional organisations and used much of the content to secure competitive STEM grant funding and achieve external education innovation awards. Similarly connection was found between STEAM and innovative pedagogy in STEAM 1, emerging in the data as the desire to "*Develop a culture of knowledge and*
1P *support among staff so that the STEAM program is seen as a part of our school culture and the wider STEM education movement*". STEAM 1 teachers benefited from actions taken to broadcast their achievements beyond the school environment: "*We weren't*
1T1 *expecting to be invited to the [name] Conference. That was an unexpected outcome. It created opportunity to share our achievements".*

Post-delivery survey data collected after the first iteration of STEAM 1 and 2 (Figure 4.34) indicated one third of the respondents (n=14) would not attempt to incorporate more STEAM ideas into future lesson design. The same data indicated 67 percent *positive* impact of STEAM learning on teacher attitudes towards incorporating more STEAM ideas back in the classroom. The cases in school settings presented many opportunities to observe how STEAM projects and activities were unlikely to succeed without communication between a range of transdisciplinary faculty inputs. STEAM 1 Principal succinctly communicated such inter-faculty frustration, "*What annoys me is that members of my senior executive and some of the other staff don't appreciate the*
1P *professional learning that has been going on here".* The data showed that STEAM PL success relied on individual teacher relationships forging strong collective goals. STEAM teacher collegiality warranted additional commitment of professional and personal energy in the attempt to convince teachers *outside* the STEAM programs of the value of authentic innovative transdisciplinary experiences *inside* the STEAM programs. Again,
1P voiced by STEAM 1 Principal as "*Resistance to connecting content, collaboration, doing*

more work, engaging with an external – all of it seems like double or triple for some teachers”.

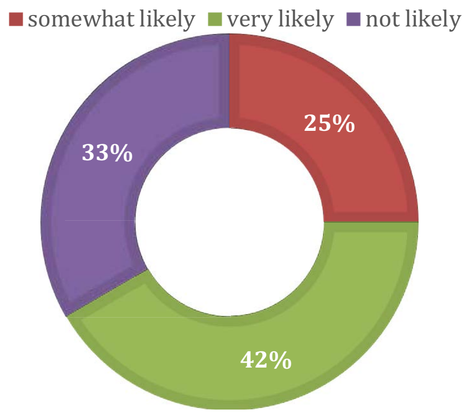


Figure 4.34: STEAM 1 and 2 post-delivery survey.

In terms of strengthening professional kudo through STEAM, comparing qualitative data from STEAM 1, 2 and 3, (school-situated settings), showed how immersive, fast-paced STEAM activities required teachers to build and fortify connections between STEAM content more readily than multi-term schedules. STEAM 2 was effectively a longitudinal case study, operationalised over three terms, with activities delivered during one lesson per fortnight. The teachers themselves expressed this model of delivery was not successful overall: *“Yep, I think immersion would be better than the longitudinal* 2T1 *approach. There were too many gaps between lessons so it was hard to maintain the connections*”. Other interviewees agreed, through discussion of the continued relevance of STEAM pedagogy at the school: “*that would make the STEAM connections more* 2T4 *impactful”*. Correlations in the data from STEAM 1, 2 and 3 found the executive message 1P from each case expressed as the desire to *“break the inertia apparent among teaching staff”*, and *“be part of the growing innovation education movement”* and *“not be left* 2T1 *behind”.* In STEAM 3, the resounding aim from participating STEM teachers expressed the goal to *“include the Arts, in the face of our established STEM partnerships telling us* 3T1 *we shouldn’t”.* The latter comment in particular signified certain fearlessness in the attitudes of the teachers. It is important to note that at the time of writing, the STEAM programs continue to be delivered at Schools 1 and 3.

4.6.5 The impact of the STEAM experience on teacher agency

The impact of STEAM learning for the participating teachers emerged in the data 1T9 through comments such as “*It’s very emotional*”; and “*Isn’t that why we’re in the game?;*

and *"What amazes me is that we did this in one group – the growth in that group*
1DP *compared to the year 8 cohort is just exponential, just because of this STEAM project"*. Understandably, the data exposed vicarious teacher pride being evident through student achievement: *"Some of them have already applied for leadership groups. The impact is huge*"; or "*I was amazed at how much these guys remembered about STEAM*
3T3 *stuff we did months ago, even the names of that shape [HP]".* Unanticipated insights found in the data showed teacher professional identity was intrinsically connected with the student STEAM experience, described by School 1 DP as:

1DP
> *"what do the students see? So, for the whole time, in their whole school life, all they've seen is one teacher up the front of the classroom, directing… being the boss so to speak. To have two or more teachers who are bouncing off each other and excited about presenting material together, you know that is really such an eye-opening event for students".*

The impact of STEAM on students at School 1 was expressed as pockets of brilliance:
1T1 "*We've discovered our diamonds in the rough early in Year 7!",* thereby creating an environment where school Principal expressed the intention: "*We don't want this to be*
1P *just a 'flash in the pan'*". Such data showed how participating teachers were steadfast in their intention to remain part of STEM/STEAM currency in STEAM 1. Concurrent with dialectical views expressed in the data from STEAM 3: "*I was hopeless at the folding but I could really see the connections with maths and science and that's how I made it*
4T2 *relevant to the students",* teachers agreed that STEAM alignment with national, economic, and sustainable goals was simply *"what we should be doing now"*. Such sentiment echoed throughout the data, surmised by STEAM 1 Principal as:

1P
> *Teacher efficacy in delivering interdisciplinary projects has increased tremendously. The program has empowered teachers to develop and grow to gain mastery of skills, knowledge in design thinking and be truly collaborative.*

The data revealed collaboration as the driver for increasing positive feelings concerning the usefulness of the STEAM programs enacted in the study. Most teachers
3T1 acknowledge that in STEAM learning "*peer support is really important. Super important*".

While risk was recorded as a factor affecting teachers' attitudes towards STEAM, its usefulness was mentioned in the data in relation to teachers' burgeoning pedagogical skill in transdisciplinary methods, leading to discussion around "*Exactly what is proper* *science and maths anyway?*. Comments from STEAM 1 demonstrated a positive response to balanced STEAM content, finding teachers stepping into more transdisciplinary roles: *"I think we have got that chemistry just at a magic level*". This view was echoed by teacher comments from STEAM 2 where small steps were characterised by subtle, unpretentious comments. For example, "*If I can make something creative and relate it back to maths, then explain that to someone else, it's still relevant maths. I can justify it. I can connect it to something in the real world and make it relevant".* Teachers who established a link between STEAM purpose and their own agency were those articulating larger shifts in identity, often unexpected and thus surprising in their emotional expression. Still it was very much the small transformations emerging from the data that led the teachers to explore other ways of viewing themselves. For example, playing around with ideas evolved organically as a result of playing in both digital spaces *and* maths-making activities. Comments exposing teachers' willingness to explore their own pedagogy, such as *"I was thinking about how we could create more stories with it. You could go in so many directions",* indicated the emergence of an *edupreneurial* sensibility. Likewise, the data showed teacher experiences of new ways of learning across subjects exposed personal affect, for example: "*I found concentrating on the maths really therapeutic, actually..."* demonstrating teachers' foray into transdisciplinarity through discovery and an expanded sense of self.

4.7 Chapter conclusion

Findings in this chapter indicated that the presence of teacher traits in STEAM professional learning were crucial to tracking transformational moments throughout the research. Teacher transformations, small and large, supported the exploration of the first research question: How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves? Qualitative methods provided a serendipitous element to addressing the second research question: How do emotions experienced during engagement in STEAM activities enhance or detract from the teachers' professional and personal identity development?. The mixed methods approach to data collection supported the investigation of complexities inherent in developing STEAM learning ecologies in each case setting. Overall, the teacher experiences collected and analysed in this research revealed fewer substantial and more subtle, nuanced changes in the behaviours of participating teachers, particularly in teachers' attitudes to challenging STEAM tasks and activities. At the edge of teachers' pedagogical comfort zones, the finding show there was personal and professional growth, even for a short time.

Overall, the findings indicated there are subtle signs we can look out for as educators when developing or co-creating STEAM professional learning. In summary, some teachers transformed into STEAM teachers for a time, while others evolved their novel STEAM understandings into sustained pedagogical practice.

As each case study in the research was enacted in traditional educational settings, it is important to appreciate that the complexity of each was not reliant on STEM/STEAM specific classroom design or innovative furniture. Quantitative measures applied in the study revealed the participating teachers found STEAM activities and learning:

1. Were most challenging and rewarding when specifically focused towards mathematics.
2. Assisted overall pedagogical and personal confidence when related to blending visual digital technology skills with STEM content and concepts.
3. Were extremely valuable for staff and students when the STEAM product was exhibited as a collective showcase to audiences external to the school environment.
4. Were dependent on collaboration and increased time to play around with ideas, if teacher ownership in terms of long-term STEAM sustainability was to be achieved.

Data collected by mixed methods provided the main body of evidence addressing the emergent assumptions inherent in both research questions. The assumptions are:

a. Given supportive conditions and opportunities, secondary teachers are motivated to collaborate in STEAM learning aligned with current transdisciplinary *innovation* education climate.
b. Transdisciplinary learning through engagement in STEAM generates identifiable shifts and changes in teacher identity.
c. Emotions experienced by teachers operating outside their specific subject expertise, increase the possibility of professional and personal transformation.

Together, the focus areas and sub-themes that emerged from the data presented three broad findings:

1. **Transdisciplinarity is a gateway for dissemination of innovative connected thinking in education contexts, encouraging teachers as well as parents and community members to understand more about STEAM learning.**

For example, increased Year 7 enrolment as a result of community awareness of STEAM PBL saw enrolments jump from 120 to 160 students over two years of STEAM implementation at School 1. Exposure of innovative practice for School 1 served to address issues with falling enrolment, while also boosting teacher morale and commitment to the school, including employment security.

2. **Acknowledging emotions experienced in STEAM learning enhanced teacher capabilities.**

A range of teacher emotions were present in the data. From teachers' excitement and willingness to 'show off' their achievements, to expressions of anxiety, frustration *and* elation felt during STEAM learning activities. Increased teacher confidence in learning and sharing new skills and expertise led to advancing employment opportunities in education innovation and leadership contexts.

3. **Co-creating for shared aesthetic outcomes expands connected cultures of thinking.**

Co-creation is currently ongoing in STEAM programs at Schools 1 and 3, including successful procurement of external grant funding to support the learning. The STEAM programs enabled sustainability with the advantage of ongoing relationships with industry and community partners.

Findings in this chapter indicated there was no question of teacher emotions being redundant in the STEAM experiences contributing to the study. Acts of mutual creation afforded teachers a greater understanding of how to develop connected curricula in STEAM learning contexts, with a view to attaining a sense of diverse generative agency for themselves. The next chapter moves on to discuss teacher transformation through STEAM co-creation with reference to current literature related to STEAM education, growth mindsets and professional efficacy. Chapter 5 considers the axiological variables associated with the STEAM case studies, respecting the fact that much of the data collected from participating teachers lies in the realms of human emotion.

Chapter Five – Discussion

"To be sunk in habitual routines, to be merely passive is, we well know, to miss an opportunity for awakening." (Greene, 2018, p. 98)

The previous chapter showed how STEAM teacher professional learning (PL) and subsequent enactment of STEAM programs in the participating schools, were influenced by teachers' *felt experiences.* Findings presented in Chapter 4 presented the ways that emotional, aesthetic and experiential elements of STEAM PL, granted many teacher participants the opportunity to experience a different view of themselves. Teachers' liminal states described in Chapter 4 ranged from troublesome to transformative. The present chapter aims to discuss those in-between states and how they affected teacher professional and personal capabilities in respect of the literature related to variables in phenomenographic STEAM learning. Chapter 5 will investigate the epistemological strength of the findings in the light of existing research in STEAM teacher learning, and in reference to two questions underpinning this study:

1. *How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?*
2. *How do emotions experienced during engagement in STEAM activities enhance or detract from teachers' professional and personal identity development*?

Three key findings will be discussed. Each key finding is supported by broader discoveries related to STEAM's transformative capacity for teachers, the importance of collegial support structures in STEAM education, and the value of recording teachers' emotions during STEAM PL. The purpose of this chapter is to determine how STEAM PL encouraged understanding of transdisciplinarity in relation to 21st century skill building for teachers. More importantly, the chapter aims to show how transdisciplinary STEAM PL contributes to the concept of 22nd century futuring, incorporating an education system within which care, connection, culture and community are of equal standing to communication, collaboration, creativity and critical thinking.

5.1 How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?

In response to this question, I have discovered insights and understanding of how the experience of STEAM learning affords teachers' shifts in identity. It is important to reiterate that seven unique STEAM projects were co-created for inclusion (see Tables 3.1 – 3.4) and that the teachers were considered the learners under scrutiny in the study. It should be acknowledged that while all teacher participants in the study knew the STEM acronym represented individual knowledge areas of Science, Technology, Engineering and Mathematics, not all teachers were aware of the Arts inclusion of Music, Drama, Dance, Visual Arts, Design and Media (ACARA, 2014a). Many participating teachers assumed the A in STEAM to be representative of Visual Arts alone. Beyond the teachers' awareness of acronyms, however, was the influence on school systems from external STEM forces, identified by Schleicher (2018) as important for economic and cultural currency. In this study, such currency was expressed by teacher participants as symptomatic of discrepant professional networks, and the passionate sentiment to not be left behind (see 4.5.4).

Encouraging teachers to step outside STEM pedagogical conventions requires them to operate in different situations, using different methods. This may be challenging and uncomfortable. Findings presented in sections 4.3.1 and 4.3.6 addressed the question of how teachers might view themselves differently through the impact of STEAM learning challenges, pressing discussion of the development of teacher self-concept across pedagogical environments and ecologies, both temporal and spatial. Biesta, Priestly, and Robinson (2015), consider such ecological conditions and circumstances as emergent transactional phenomena, stemming from pragmatic Deweyan contexts, in that teacher responses are shaped by exposure to problematic situations (Biesta et al., 2015). Hattie (2016) says "The greater the challenge, the higher the probability that one seeks and needs feedback" (p. 18). Consistent with Hattie, the challenge for teachers participating in this research was peer coaching the integration of STEM content, skills, techniques and terminology with elements from the Arts curriculum. This required teacher effort and communication beyond an individual desire for achievement, applause or accolade. Encouragement occurred by virtue of teachers' collective goal setting, reflecting views held by Donohoo (2017), who recognises the fact that fostering collective efficacy is "increased through vicarious experience – when witnessing someone, facing similar circumstances, meeting with success" (p. 64). The research findings showed consistency with this view. In this study, the 'problematic situation' proposed by Biesta et al. (2015) was how to encourage *all* participating teachers to operate outside conventional pedagogy. Indeed, even outside STEM conventions, with a view to enabling teachers to think differently about integrated pedagogy, themselves, and the world, avoiding what Eagleman and Brandt (2017) observe as predictability and repetition.

5.1.1 STEAM learning has transformative capacity for teachers

The most frequently asked question during teacher PL at the onset of this research, was from the uneasy perspective of "*Why are we doing this*?" (see 4.4.9). The transformation of teacher unease to enthusiasm (see 4.3.8 and 4.4.13) was made possible through renewed expression of purpose, pedagogical ownership, and the wisdom of collective efficacy. Nurturing teachers' growth mindset through STEAM PL was unquestionably related to challenges encountered through the use of technology as well as making by hand (see 4.5.3, 4.3.1, 4.3.6). Over time, the participating teachers acknowledged new aspects of pedagogical skill that were previously untapped. The relationship between the teachers' commitment to STEAM 'in theory' and the realisation of how the STEAM activities were to be enacted, firstly drew responses that were steeped in fear and anxiety. These are discussed later in this chapter, however must be mentioned here because the incorporation of STEAM's 'hand-made' experiences play an important part to teacher transformation. Teachers' curiosity related to 'maths-making' in STEAM (see 4.4.6) provided key inputs to the value of the many *in-the-moment* learning experiences recorded in this research. Experiences referred to by Dewey (1938) as 'erlebnis'. Such experiences rely on a degree of teacher curiosity, which was difficult to measure through qualitative methods due to its human essence being intrinsically personal. Therefore, locating examples of curiosity through observation of progressive STEAM PL activities called for diligence in recording specific nuanced 'erlebnis' teacher experiences. In this way, it was possible to interpret teachers' curiosity as a burgeoning sense of creativity. In the STEAM learning undertaken in this research, creativity was generally considered problem solving via *making*. In accord with recent studies in science and art 'creativities', disciplinary change occurs as a process of making, where "value is placed on the experimental and material agency of invention and exchange between arts and science creativities" (Burnard & Colucci-Gray, 2020, p.424). Certainly, as the research progressed, the teachers became more inventive and fearless (see 4.5.5), demonstrating how STEAM's purpose, in response to 'why are we doing this?', is as much about 21st Century skill construction for *teachers* as it is for students.

Teachers evolving new STEAM capacity and pedagogical skill were physically manifesting STEM content via the action of *making*. They were embedding the experiential A in STEAM, often without realising (see 4.5). The literature views this as the craft of visible, representational learning (Gettings, 2016; Hanney, 2018; Hunter, 2015), or the aesthetic output (Hanney, 2018), unquestionably influenced by flow theory and the consideration of the aesthetic *experience* (Csikszentmihalyi, 1996; Kerdeman, 2009; Robinson, 2001). Examples from the data found a range of modalities represented the practice of making in STEAM education. For example, STEAM as metaphor allowed for exploration of biomimicry in 'Binary Bugs' (see 4.2.2), storytelling in 'Hyperbolic Paraboloids' and 'Flextales' (see 4.2.4 and 4.2.7), geolocation in 'This is Me'(see 4.2.5), and futuring in 'STEAM City' (see 4.2.3). The concept of metaphor and speculation increased the relevance of maths-making as participating teachers expressed curiosity for how specific activities worked, in particular, the mechanics of paper folding (see 4.2.1, 4.2.2, 4.2.4, 4.2.7) and augmented reality technology (see 4.2.5), and how the concepts could be applied in contexts individual to each case. This finding parallels innovative practices developed by researchers in the field of embodied or applied mathematics (Fenyvesi et al., 2020; Silk, 2018; Spreafico & Tramuns, 2020), multiple creativities (Burnard & Colucci-Gray, 2020) and the relationship between the body and the brain in STEAM learning (Eagleman, 2018; Leader, 2016; Sousa & Pilecki, 2013).

The application of *erfahrung*, in the research analysis was equally valuable to understanding how STEAM learning has the capacity for teacher transformation. Erfahrung is the German word interpreted by Dewey (1938) as 'reflective and cumulative experience'. Collecting teacher experiences post PL and delivery to students provided evidence of the effectiveness of co-creating the STEAM activities for this research, as well as exposing the subtleties of the teachers' fear-to-fearlessness journey. The co-designed STEAM activities attempted to connect multidisciplinary and multisensory learning by using multiple concepts and methods (see 4.2). The complexity of the research design (see Figure 3.3) was echoed in the complex range of activities enacted in STEAM 1 and 2 specifically. Maintaining the STEAM connections made through enacting such complex transdisciplinary projects would require continued teacher curiosity, fearlessness and passion, three of the attributes considered by Wagner (2012) as essential for innovation. Erfahrung data, collected from these cases, and STEAM 3 and STEAM 4, identified how teacher ownership and STEAM sustainability was at first, terrifying, but over time, became clearer in its purpose and posed an achievable outcome. As Wagner puts it: "it is really in the doing – in the probing of the universe, the pursuit of a query – that the real learning takes place" (Wagner, 2012, p. 156). The coaching model applied in teachers' STEAM learning assumed the same schema in the delivery to students, where teachers' became the "guide on the side" (Fenyvesi et al., 2020; Wagner, 2012, p. 161) rather than distributors of information. In this way, the STEAM learning enacted in the study was consistent with literature that renders the pursuit of a query as collaborative, stimulating insights from teachers and students both in the moment, and after the event.

The fear to fearlessness journey that emerged from this research, was for many of the participating teachers, a concerted attempt to tackle STEAM's so-called 'wicked problems' head on, as Bernstein (2015) would say (see Table 4.1 in 4.4.12). A consistent challenge throughout the study was relating STEAM learning to real world contexts (see 4.3.8), and in transdisciplinary discourse, Cranny-Francis (2017) and Mau (1998) also term such challenges as 'wicked problems'. Each contend the word transdisciplinarity itself, poses a 'wicked problem' for educators. The teacher experiences recorded in this research determine their contention to be true. Wicked problems are used in design and systems thinking methodology (Avital & Te'Eni, 2009; Gross & Gross, 2016) across a range of industries. In this research, using design thinking tools during STEAM PL resulted in teachers' willingness to attempt innovative practice or new pedagogical approaches, primarily by collaboration, across multiple angles. Section 4.5.1 shows how design thinking has crept into PL terminology in schools, albeit inciting a noted amount of teacher apprehension. Nonetheless, in this research, using journey mapping in STEAM

PL, a key design thinking tool, resulted in direct examples of teachers' empathetic concerns for students, to be a corollary of their own disquiet and fears (see 4.4.17). Regarding empathy, findings across the cases support Hattie's (2012) argument that teachers with the capacity to see learning through the eyes of the student, including how they are thinking, indeed recognise opportunities for their own thinking to be enhanced.

Encouraging the transferral of subject specific knowledge across STEAM contexts afforded the participating teachers new understanding of how to establish connections between concepts that apply to real world problems, each a hallmark of innovative pedagogy mandated in Australian curricula (ACARA, 2014b; NESA, 2017). My research found that participating teachers regarded the application of STEAM in real world contexts was not only important, but absolutely necessary (see section 4.3.3). The teachers' desire to know, connect, and apply creative STEAM learning in relevant real-world contexts was discussed in terms of potential knowledge transaction during PL across the case studies. Thus confirming Bernstein's view of transdisciplinarity being "as much about the liberal arts, and about cultural symbolisms, as it is about the so-called social and natural sciences, or professions like medicine, engineering, or law" (Bernstein, 2015, p. 5). Certainly, the knowledge transactions, haptic engagement, curiosity, risk-taking and imagination investigated within teacher PL in this research, is aligned not only with literature related to transdisciplinarity, but also with literature related to multiple creativities and the inseparable link between neuropsychology and physical activity (Fenyvesi et al., 2020; Fiorilli et al., 2015; Gulliksen, 2016; Pallasmaa, 2009). Relating the STEAM ideas underpinning the activities in this research to the real world, evolved and nourished a deep, active and connected engagement for most teacher participants (see 4.4.13). Such engagement advocates a process where teachers' curiosity, persistence and fearless interactions direct the learning towards sustained periods of 'asking why?' (Anderson & Jefferson, 2016), and 'what if?' (Craft, 2015). During these periods, unsolicited 'think aloud' moments, expressed as erlebnis (in-the-moment experiences), as well as cumulative reflective experiences – erfahrung (Dewey, 1938), were documented and analysed (see 4.3.7, 4.5.1). The findings showed how STEAM learning deeply enriched the participating teachers' curiosity (see 4.4.6), offering dual conditions to think *and* to make (Kalbstein, 2015). Increased curiosity afforded teachers' appreciation of ‘connections’ and ‘making’ as transformative, while they navigated different epistemologies to make sense of the STEAM learning in relation to shifts in personal and professional identity.

5.1.2 Transdisciplinary STEAM provides a gateway for teachers to develop innovative connected thinking

Stepping outside the comfort of knowledge expertise opens pedagogical possibilities for teachers working in a STEAM integrated environment. This section of the chapter explores the teachers’ response to and engagement with transdisciplinary education challenges undertaken in the research, in relation to the concept of innovative pedagogical practice. It is important to reiterate that the seven STEAM projects developed for research inclusion were unique to this research (see Tables 3.1 – 3.4). This study was designed to determine the effect of STEAM learning in terms of co-creation with participating teachers, consistent with Pallasmaa’s (2009) investigation of spatial and temporal relationships in the execution of a task, and studies of the development of creative learning ecologies (Craft et al., 2012; Paavola et al., 2004). That is, the who, what, how, where and why, associated with developing and delivering STEAM projects. STEAM was a new experience for all participating teachers (see 4.4.6, 4.4.14), and unbeknownst to them, operating collaboratively to co-design effective STEAM pedagogy, demonstrated the reality of innovation described by Paavola et al. (2004) as “being a label to what we were actually doing” (p. 557). Wagner’s (2012) fifth innovation attribute – purpose – emerged in the participant teachers’ commitment to STEAM. Sections 4.4.16, 4.5.3 provide evidence of teachers’ personal and professional insights recounting STEAM learning experiences through *erlebnis* and *erfahrung,* or empirical understanding. If the teachers considered the concept of innovation as something new or improved, transdisciplinary STEAM activities enacted in this research fell neatly into such consideration. Hattie (2017) claims we have few debates about the quality of implementing new ideas in teaching, and barely developed literature related to scaling up excellence. Liao (2016) agrees, arguing the diversity of arts-integration renders it difficult to locate and pinpoint best practices. Still, in an accelerating STEM education climate, there are growing numbers of STEAM practices and studies similar to my own, that broadcast the achievements of motivated teachers and researchers (Burnard & Colluci-Gray, 2020; Fenyvesi et al., 2020; Keane & Keane, 2016; Lemon & Garvis, 2015;

Spreafico & Tramuns, 2020; Yakman, 2008). The teachers who willingly pushed curriculum boundaries to participate in this study have contributed to that body of knowledge.

For the participating teachers, acknowledging the relationship between STEAM and innovation relied on their willingness to think conceptually and construct logically, together. The teachers benefitted from a fundamental practice of innovation being the opportunity to ask questions, take risks, and discover things for oneself, as the literature suggests (May, 1975; Priestly, 2015; Tait & Faulkner, 2016; Wagner, 2012). Indeed, May (1975) argues that risk encounters give rise to works of great creativity. The teachers participating in large scale STEAM programs in STEAM 1, 2 and 3 in particular, affirm May's view (see 4.2). Accordingly, Wagner (2012) considers creativity intrinsic to a person's desire to innovate, often embracing passion and interest, sparking individual or collaborative challenge and the desire to achieve. Section 4.3.8 demonstrates how the combination of teachers' conceptual thinking and logical construction during transdisciplinary STEAM learning incorporated authentic altruistic features of collaboration. Prentki and Stinson (2016) claim transdisciplinary authenticity requires rejection of neoliberalist approaches to learning, where individualised modes of thought have obstructed the flow of knowledge connections between learners, and also between the learner and their world. In contrast, this study shows how a measure of individualism *was* necessary for effective STEAM collaboration, as the teachers themselves benefitted from paying special attention to the way each individually described and interpreted STEAM phenomena and problem-solving situations (see 4.4.17). Aligned with views held by Schleicher (2018) and Ritchhart (2015), such individualism was necessary for the participating teachers' understanding of STEAM learning experiences from the unique perspective of others. In this way, many of STEAM's innovative characteristics were experienced by proxy, and the collective passion for STEAM learning began to flourish.

Teachers frequently described their passion in terms of service to students, associating passionate teaching practice with evidence of its effect in the classroom (see 4.4.13). Students typically associate their teachers with a particular subject (Kessels & Taconis, 2012), which upholds the self-concept many teachers have about their own knowledge and ability, area of expertise and professional comfort zone (see 4.3.8, 4.4.6).

However, Hattie (2012) emphasises how little effect the teachers' subject matter knowledge actually has on student outcomes, saying a passionate teacher communicates "the excitement of the challenge, and their commitment and caring for learning" (p. 31). Bonneville-Roussy, Vallerand, & Bouffard, (2013) observed that students who perceived their teachers as collectively passionate and autonomy supportive, experienced similar positive emotions, flow or concentration, influencing both teacher and student subjective well-being and life satisfaction. Certainly, the serendipitous moments of excited pedagogical discovery observed in this research supported views held across the literature that STEAM learning affords teachers broadened opportunities for innovative pedagogical invention (Burnard et al., 2018; Craft, 2015; Herr et al., 2019; McAuliffe, 2016; Quigley & Herro, 2016; Vallerand, 2015), consequently encouraging teachers' innovative connected thinking.

5.1.3 Awareness of teacher 'traits' in STEAM PL highlights the importance of nurturing collegial support structures

The emergence of teacher 'traits' in this research was fundamental to the notion of shifting teacher identity. The range of traits encountered were not unique to STEAM in particular, but prevalent in human nature. The *neat-freak*, *bull at a gate*, *formula-maker*, *nervous perfectionist*, *panicker*, *resistor*, *saboteur*, and '*edupreneur'* were the groupings in which I playfully categorised certain teacher behaviours based on observation during STEAM PL, and the collegial banter shared by the teachers themselves (see 4.3.4). Associated closely with self-concept, the identification of 'traits' highlighted certain shared human characteristics, as opposed to the teacher characteristics Carlone and Johnson (2007) recognise as a 'science person' or a 'maths person' for example. Moving away from observing the teachers' behaviour according to expertise or skill in a specific knowledge domain, supports the literature stating that identity is constantly reconstructing, adapting and evolving (den-Brok et al., 2010; Krause et al., 2003). Findings presented in Table 4.2 further support such views and align with Kessels and Taconis' (2012) notion of identity as composed of values and norms, ways of seeing, knowledge of the self, including ways of knowing, and ways of doing. One contrasting result that questions this notion was the emergence of 'saboteur' as a teacher type. Section 4.3.7 presents the saboteur as resistant, according to peers and behaviour, when in fact the teacher in question was quietly interested all along. Craft (2015) would see this as “the notion of multiple selves, of which the transcendent and rational is simply one” (p. 84). Similarly, Palmer (1997) directly links a form of ‘transcendent self’ with the notion of identity, defining identity as “the irreducible mystery of being human” (p. 5). The contradiction inherent in the saboteur teacher type, while difficult to consider transcendent, was definitely mysterious. Consistent with the literature (Krause et al., 2003; Marton, 1988; Timm et al., 2016), is the in-between concept that connects a person to an environment or context, and in this study, the phenomenographic sense of the teachers’ self-identity was comprised of many dimensions and entities (traits), based on development and interaction with the world over time, continuously related to the context within which the teacher grows and acts.

The relationship between teacher ‘traits’ and the STEAM learning circumstances that incorporated Burnard and Colucci-Gray’s (2020) notion of multiple creativities, was key to developing teachers’ attitudes of fearlessness in the face of ‘not knowing’ (see 4.5.3). The work of Paavola et al., proposes creative learning ecologies are “not laden with epistemological and ontological weight in terms of the theories of knowledge” (Paavola et al., 2004, p. 557), but rather acknowledge human characteristics emanating in situations where cerebral or physical challenge was an essential part of the new experience. In accordance with this view, teachers stepping outside comfort zones in this research, created opportunities to grow on a personal level as well as professional (see 4.4.17). As expected, troublesome aspects of uniting STEM content with the Arts reflected views held by Bequette and Bequette (2012), that while some teachers liked the idea of STEAM, they were often put off because of its perceived lack of specificity. Section 4.5.3 demonstrates the value of establishing specificity through nurturing a growth mindset in STEAM learning, and applying STEAM to real-world contexts, or in familiar real-life situations. In this way, content connections emerged, resulting in teachers’ pushing themselves beyond established pedagogical comfort zones, and separating from a self-confessed ‘type’, albeit momentarily (see 4.4.15).

The shared experience of the *panicker*, or *formula-maker*, for example, aligns with May’s (1975) view of creative encounters producing a great degree of anxiety and agony. Different examples from the literature would agree (Glăveanu, 2019; Paavola et al., 2004; Roth, 1998), stating that teachers’ effort in the pursuit of newness in STEAM, including creative risk-taking in terms of different ways of perceiving learning and knowing, leads to discovery, personal achievement, organisational practice and new forms of activity which are simply 'not there yet'. Dweck (2008) would position such effort *outside the comfort zone.* Other studies would say the language of this cognitive strain comes from discrepancies and tensions inherent in personal development (Kahneman, 2011; Woods & Carlyle, 2002). That "central, private region of our life" (Krause et al., 2003, p. 71) defining the teaching identity as balancing perspectives between personal and professional characteristics (Timm et al., 2016). The teacher traits acknowledged in this study fall neatly into these reference zones, and awareness of such traits emphasises the fact that teachers collaborating in STEAM do not have to operate alone.

Establishing collegial support structures for the teachers participating in this research, brought transformational affordances, large and small. Findings related to the impact of STEAM collegiality and collaboration in Sections 4.5.4 and 4.5.5 showed how STEM teachers participating in the research benefitted as much as non-STEM teachers, dismantling the siloed approach to subject content that hinders what Golden (2018) and Ritchhart (2015) identify as the opportunity to create a connected culture of thinking. Accordingly, Table 4.2 demonstrated how teachers were transformed through STEAM engagement, in alignment with Roth's (1998) fundamental concern with creating effective communities of practice, and what Barniskis (2014) calls "a STEAM-charged participatory culture" (Barniskis, 2014, Para. 2). As individual teachers were interacting in ways they had not before, much of the teacher behaviours, as expected, reflected Arnsten's (1998) analysis of human types in the *Biology of Being Frazzled*, where frazzled is a neural state in which a person cannot think clearly or concentrate. Section 4.3.1 presents examples of such frazzled states, confusion, and a sense of being 'time-poor'. Consistent with the literature related to framing STEAM learning in the right kind of pedagogical process (Glass & Wilson, 2016; Goodwin, 2012; Housen, 2002; Soh, 2017), the research findings acknowledged how STEAM learning can be time consuming and difficult to manage in terms of human and non-human resources. While the findings demonstrated how feeling frazzled amidst the challenge of STEAM initially permitted the teacher traits to increase in individual prominence, the effect of positive collegiality noted by previous studies (Fiorilli et al., 2015; Liu et al., 2018) engendered an understanding of how each type contributed to the overall accomplishment and transformation of the group. Craft (2015) argues the excitement attached to teachers' self-classified transformative experiences, is apparent in creative action-based pedagogy. This is the type of learning within which experiences are co-created from multiple perspectives, engaging multiple creativities, as Burnard and Colucci-Gray (2020) suggest. Indeed, the STEAM PL enacted within this study portrayed such actions and creativities. Moreover, Table 4.2 demonstrated how kudos associated with making change, or being acknowledged as 'change agent', a type of teacher recognised by Tait and Faulkner (2016) as 'edupreneurial', was a key motivator for the teachers to continue STEAM programming into the future, demonstrated by the desire to "*Bring it on!"* expressed in Section 4.5.4.

The contribution this research makes to a STEAM-favoured education future is to be aware of the identified teacher traits in creating challenging STEAM PL, and to manage such teachers with empathy and care. Findings in Section 4.3.7 and 4.4.13 presented examples of individual and collective transformation, large and small. Empathetic behaviour observed through teacher peer-to-peer and peer-to-leader interactions were prevalent across the cases (see Section 4.3.7, 4.4.13, 4.5.2), supporting Liu et al.'s (2018) view that education futures might include more acts of care that enhance individual and societal wellbeing, by bringing the individual in meaningful connection with a relational connective balance (see Figure 5.1). In this study, the *panicker*, *perfectionist* and *resistor* were gently encouraged to transform through empathetically acknowledging that their own contribution and success in STEAM correlated with the student experience: *"and these are not our top kids*". The self-doubt or trepidation initially felt for STEAM learning (see 4.3.7, 4.4.15, 4.5.3) afforded many participating teachers an understanding of the perspectives and emotions of others, including students, when faced with the possible emergence of transdisciplinary-oriented education futures. Accordingly, the literature argues the provision of transdisciplinary learning for both teachers and students must be developed in caring, integrated circumstances in which co-construction is balanced and contributory (Craft, 2015; Ingold, 2020; Liu et al., 2018; Tait & Faulkner, 2016). My research proposes that *all* types of teacher have something unexpected to contribute as well as something to gain in STEAM learning.

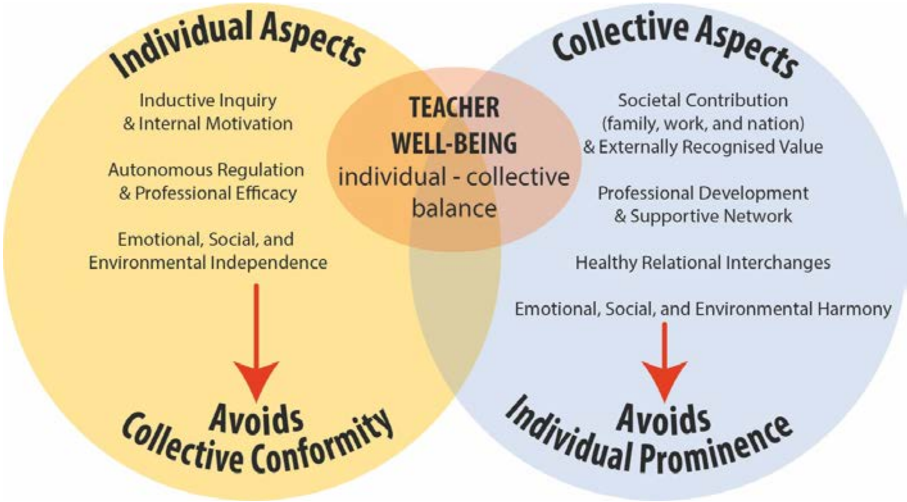


Figure 5.1: Teacher Wellbeing = individual – collective balance (Adapted from Liu et al., 2018)

5.1.4 Co-creating for shared aesthetic outcomes expands teachers' connected cultures of thinking

Possibly the best feature of STEAM is its default position spanning discipline boundaries, which for secondary school teachers not considered 'generalists', demands communication and collaboration with peers, sideways to their own knowledge and expertise. Addressing the first research question, the potential aesthetic outcome of STEAM PL was not clear for the participating teachers at the beginning of the study. By this, I mean the STEAM artefact, aesthetic product, or exhibitable work created through STEAM. Over time, the teachers' actions and perspectives were underpinned and reinforced by novel expectation, imagination, organisation and judgement (see 4.3.2). Such actions support Craft's (2015), emphasis on choice being paramount to the 'orientation of the creative', even if the potential outcome of the creative orientation is not clear (Craft, 2015, p. 85). In alignment with Csikszentmihalyi's (1996) notion of flow, and Robinson's (2001) view of creativity, a parallel outcome for the teachers was the aesthetic experience itself. What did become clear, was how the participating teachers constructed new methods of collective and collaborative pedagogies in order to disrupt their own conventional historical models of learning and teaching (see 4.3.1). Schleicher (2018) and Sahlberg (2010), in discourse related to the vocation of teaching, proposes this to be the development of an informed profession, encouraging abandonment of former prescriptive behaviours. In the same way, scholarly work by May (1975) and Palmer (1998) see such abandonment as "temporary rootlessness" (May, 1975, p. 39), or “an insightful positive force” (Palmer, 1998, p. 39), considering both as fundamental to the notion of nurturing teacher identity.

The benefits of authentic STEAM collaboration, where cross-curricular inputs are balanced, were apparent in teachers’ attitudes and confidence after STEAM PL enacted in this research. Barniskis (2014) says there is confidence in building a team. Tait and Faulkner (2016) argue that innovative teachers grow in confidence when they find and are supported by those who share the same unconventional perspective. The research findings do not suggest that *all* teachers participating in this research were unconventional (see 4.3.1, 4.3.6, 4.4.17). What the findings demonstrate rather, is that participating teachers began to understand their value to the STEAM programs, by virtue of a willingness to engage with meaningful thinking and making situated outside personal and professional comfort zones (see 4.5.1). Such thinking and making is crucial to human investigation, interrogation and reinvention, as Patton and Knochel (2017) suggest. This is in alignment with Stinson (2013), who sees the team having its roots in the notion of relational pedagogy. In the context of this study, relational pedagogy was the understanding of what it is to be human first, prescribing learning and teaching experiences as a natural evolution of our relationship with the business of living. The teachers’ new sense of professional and personal identity evolved through curiosity, was powered by supportive kindred spirits and co-creators.

In terms of teachers exploring other ways of viewing themselves in a collaborative setting, what transpired, by default, was the pursuit of what Campbell (2018) calls a personal ‘pedagogical bricolage’. Anderson and Jefferson (2016) argue it is the responsibility of the teacher to resist superficial engagement, intensified by socio cultural phenomena, and structure more opportunities to notice more, look deeply and make connections. Purposeful collaborative integration within challenging and conflicting demands of the STEAM learning ecology developed in this study, likewise to Anderson and Jefferson (2016), reflected views held by Fenyvesi et al. (2020) Campbell (2018), and Lemon and Garvis (2015), asserting a teacher’s self-belief is positioned far from the individualistic technicist view of teaching. Such studies view teachers as ‘extended professionals’, continually faced with defying conservatism and finding new depth in teaching practice. The STEAM teacher learning undertaken in this study supports such views.

Evolving a connected culture of thinking through STEAM learning, warranted additional commitment of professional and personal energy in the attempt to convince teachers *outside* the STEAM programs of the value of authentic innovative transdisciplinary experiences *inside* the STEAM programs. Section 4.5.4 finds that in STEAM 2, participating teachers themselves considered the longitudinal model of delivery to students as ineffective compared to an immersion model (STEAM 1 and 3), primarily due to gaps between STEAM learning sessions where content connection was not sustained. This supported previous studies finding the sustainability of creative and innovative teaching and learning depends on the continual maintenance of interrelated elements. These elements not only include knowledge content, but also play, passion and purpose (Craft, 2015; Ninkovic & Floric, 2018). Findings in 4.5.4 are consistent with studies related to sustaining curiosity (L. Campbell, 2018; Housen, 2002; Manguel, 2015; Rahm, 2016; Soh, 2017; Sterling, 2015), and fearlessness (Bereczkia & Kárpátib, 2018; Schleicher, 2018; Soh, 2017), defining both as very human contributions to STEAM learning "*that would make the STEAM connections more impactful*". In my research, correlations with Ninkovic and Floric's (2018) view of teachers' playing with ideas, materials, tools, and with each other were evident in the discussions of STEAM sustainability, where the collective activity was grounded in a high level of coordinated collaboration, as Ninkovic and Floric (2018) suggest. The post-delivery data indicating how STEAM learning did not motivate *all* of the teachers to continue to pursue their personal pedagogical bricolage, as Campbell (2018) puts it, did, however, indicate how a treasury of STEAM ideas *was* motivating for some of the teachers, even for a short time.

5.2 How do emotions experienced during engagement in STEAM activities enhance or detract from teachers' professional and personal identity development?

Varying degrees of teacher emotionality recorded in the study indicated the potential for activity emotions to be catalysts for changing the way the teachers viewed themselves, and in relation to others. Participation in STEAM learning, for the teachers in this study, was not a moderate activity. Emotions presented in section 4.4 cycle through expressions of joy, empowerment and care, enacted via play, curiosity, fearlessness, and passion. These are in alignment with Wagner's (2012) attributes of the innovator. Simultaneously, it is important to acknowledge how emotions of anxiety, fear, fatigue and frustration made equally powerful contributions to forming teachers' pedagogical bricolage, supporting Ackerman's (2000) view of fearless educators as those who choose to reject the act of teaching as "an exercise in moderation" (p. 196). Wagner (2012) and Ohlsson (2011) agree that teachers who collaborate for innovation, embrace a level of fearlessness as they dive into the deep end of learning. In line with these views, a new sense of teacher professionalism emerged in the study, one that embraced risk, change and the anxiety accompanying a world, according to May "not as we experienced it before" (May, 1975, p. 93).

In terms of the relationship between play and STEAM, the temporal circumstances intrinsic to the teachers' experience in this study resulted in conditions of obvious emotional contagion. See for example, comments in sections 4.3.1 and 4.4.3. Play forced a constant dialogue between the eye, mind and hand. Teacher participants faced the same expectations as their students, supporting what Maeda (2012) calls 'critical thinking - critical making'.

> "It's an education in getting your hands dirty, in understanding why you made what you made, and owning the impact of that work in the world. It's what artists and designers do" (Maeda, 2012, Para. 4).

Regarding the construction of a teacher's pedagogical bricolage, in relation to enhancing or detracting from personal or professional identity, the action of play in STEAM influenced teachers' contextual opportunities to work with a wide variety of new materials, tools and techniques, under a range of different conditions. As expected, the literature views this as a teacher's willingness to explore, or play around with ideas (Ackerman, 2000; Craft, 2015; Soh, 2017). In this research, teachers' exploration of STEAM theory and associated making activities, not only encouraged a willingness to play, but also the activation of curiosity, fearlessness and passion, as Wagner (2012) suggests. Play, therefore, pressed the *edupreneur* out of the *formula maker*, *panicker*, *nervous perfectionist* and *resistor*, enabling the teachers more sense of what Kahneman (2011) calls 'cognitive ease' (see 4.4.2, 4.4.3).

Transformation from confusion to clarity, presented in Table 4.1 demonstrated how emotions recorded during participant teachers' reflection on practice, led to insights aligned with Wagner's (2012) view of *fearlessness* in particular. Teacher confusion and anxiety during initial STEAM PL was managed skilfully and carefully by those leading the programs in STEAM 1, 2, and 3. This approach was based on relational equanimity. There was no hierarchy in the STEAM teacher collaborations, consistent with Craft, Chappell, Rolf, and Jobbins' (2012) consideration of collaboration in the face of perceived overwhelming obstacles, permits teachers to "produce something novel and inspirational" (p. 119).

The teachers' self-perceived uncertainty gave way to a new sense of professional identity as the study progressed. Findings in section 4.4.2 verify the emotional value in effort and support the connections between teachers' emotions, thinking and intention so important to Greene (1998) and Jaggar (1989). Emotions, particularly *outlaw emotions* viewed by Jaggar (1989) as fear, irritability, ridicule, (see 4.4.12 and S2/T3 in 4.4.15) or those "outside emotional hegemony" (1989, p. 160), provided the means for participating teachers to perceive the world differently "from its portrayal in conventional descriptions" as Jaggar suggests (p. 153). Alike in ferocity, bold emotion-rich claims such as those presented in section 4.4.16, uphold Palmer's (1997) views on the heart of teacher identity being enquiry, the human characteristic of curiosity, before being a method or framework for asking questions. Novel enquiry takes courage to enact and as such, is an emotional and sometimes spiritual element of STEAM teaching. Palmer (1997) interprets this as "the diverse ways we answer the heart's longing to be connected with the largeness of life – a longing that animates love and work, especially the work we call teaching" (p. 2).

5.2.1 Embracing dialectical emotions experienced in STEAM learning enhances teacher capabilities.

In STEAM learning, if there is an emotional value in effort, the same can be said for productive persistence and fearlessness. Anxiety over STEAM co-creation and ownership was noted particularly in STEAM 1, 2 and 3, (school-based case studies), where nearly three quarters of participating teachers had no experience of STEAM. Collaboration, even working in pairs, increased teacher perseverance and lessened individual fear as the STEAM PL and programs evolved (see 4.4.12). According to Timm et al. (2016), the intention of teacher ownership is to extend and enable the brand of teaching itself. Therefore, in regard to the second research question, embracing fearlessness was crucial to the sense of 'ownership' of the STEAM learning undertaken in this study, as it demonstrated how the inseparability of person and profession determines the investment in the ownership and evolution of work. The transition from fear to fearlessness presented in section 4.4.12, reinforced how teacher collaboration and altruistic leadership augmented the transformative STEAM experiences for teachers in the study. This is affirmed in the finding the emotions supporting individual and collective fearlessness a generative and powerful innovation attribute literature (Hattie, 2017; Koeslag-Kreunen et al., 2017; Tait & Faulkner, 2016; Wagner, 2012).

The contradicatory analysis of observational data and comments collected in STEAM post-delivery interviews, was key to understanding how the teachers' emotions were being processed as the research progressed. Teacher silences were initially interpreted as anxiety, and later resolved to engagement (see 4.3.7), supporting Cranny-Francis' (2017) view of balanced representation in transdisciplinarity, is where the loudest voice should be that of the softest speaker. It was the challenge inherent in STEAM learning that questioned the teachers' purpose, perseverance and grit, if ownership of the learning was to be achieved. Prior studies have noted the importance of grit, or perseverance in the development of personal identity (Bonneville-Roussy et al., 2013; Duckworth, 2016; Sousa & Pilecki, 2013). High levels of teacher perseverance, observed across the cases in this research, support such studies. Perseverance afforded the participating teachers expressing self-perceived 'average talent', greater creative success, over those with self-perceived high talent and little grit. Duckworth (2016) considers the combination of the latter to result in the tendency to give up "while the former persevere to finish the task" (in Sousa & Pilecki, 2013, p. 154). In this research, teacher perseverance was synonymous with grit, and both were measurable, as Duckworth (2016) claims (see 4.4.7). The so-called 'bloody miracle' (see section 4.3.6) achieved in STEAM 1 by unencumbered perseverance, further supports Duckworth's claim. This finding and those expressed in 4.3.4 demonstrated teachers' self-perceived limitations. While sometimes observed as 'hysterics' in the teacher traits outlined in 4.3.4, were dialectically, expressions of grit.

The teachers' emotional responses to STEAM learning were frequently dialectic. Section 4.4.2 and 4.4.7 present these through a range of teachers' *felt* experiences – activity emotions. The literature identifies activity emotions in the context of control-value theory (Schulz & Pekrun, 2007), and theories of fixed mindset versus growth mindset (Dweck, 2008), where the exploration of social emotions intersecting with achievement emotions, finds "emotions are grouped according to their *valence* (positive vs. negative; or pleasant vs. unpleasant" (Schulz & Pekrun, 2007, p. 15). My research findings support such views. The teachers' actions and responses observed throughout the study correspond with Dweck's (2008) research on growth mindsets. Dweck proposes that a growth mindset allows a person the "luxury of becoming" (Dweck, 2008, p. 25). In the same way, section 4.5.3, showed how individual teacher's growth mindset was nurtured as the study progressed. Transformation, surprising even to the teachers themselves, is also related to Greene's sense of incompletion, "I am who I am not yet" (Pinar, 1998, p. 1). Greene (2018) urges teachers to make their work an object of experience, letting energy pour in, to give life to the experience. The dialectical observations presented throughout the findings displayed variants of Greene's view.

Enhanced teacher capabilities, including physical *and* emotional experiences in STEAM learning, were observed as a sense of 'becoming'. Experiences related in section 4.5.1 showed how teacher transformation was inclusive of complex and automated metabolic processes operating at their peak, as Csíkszentmihályí (1990) and Robinson (2001) describe. Such peak emotions were portrayed dialectically by the participating teachers themselves (see 4.4.5), aligned with a prevalence of Jaggar's (1989) aforementioned 'outlaw emotions'. Teacher emotions such as boredom, frustration and anger, also prevailed in the study, countering expressions of teacher's grit, persistence and feelings of pride and joy (see 4.4.16). Notwithstanding, the teachers were observed as able to positively embrace the STEAM learning experiences when perceived as challenging, difficult, and joy-less, or when specifically related to mathematics, as Holdener (2016) says, "even scary" (p. 2). Moreover, sharing the fear and anxiety related to STEAM learning, halves it (see 4.5.2). Likewise, teachers expressing the joy and elation of achievement in STEAM learning, increased in confidence and skill, developing the potential to emerge as *edupreneurs.* That is, the teacher type recognised in the literature (Bell, 2017; Craft, 2015; Liao, 2016; Tait & Faulkner, 2016) as exhibiting all the hallmarks of the innovator: willingness to play, openly curious, visibly passionate, and fearless in the face of resistance or 'not knowing'.

The STEAM teacher PL enacted in this research encouraged the emergence of edupreneurial behaviour as the study progressed. This was no better represented than in the case of STEAM 1, where specific teachers wholeheartedly embraced STEAM PL to greatly benefit from developing a stronger sense of self (see 1T6 in 4.4.6), as well as collective efficacy (see 4.4.14). Self-efficacy theory proposes that personal accomplishments, vicarious experiences and types of persuasion are included in methods of personal self-appraisal (Maltz, 2015; Romero et al., 2012; Schunk, 2011), and although it is proven that successes raise efficacy and failure lowers it, "once a strong sense of efficacy is developed, a failure may not have much impact" (p. 208). Schunk's ideas align with the transformation of teacher traits outlined in the section 4.4.12 where the fear to fearlessness journey included the release of teachers' fear of failure in this study.

Individually, fear, anxiety and trepidation materialised in the study during instances of teachers' hands-on learning (see 4.4.7). Teacher hesitancy emerging through these outlaw emotions slowly acceded to confidence, due directly to collegial interactions. Aligned with studies suggesting a typical view of the STEM professional as one of "detached individuals governed mainly by facts and empirical data" (Sousa & Pilecki, 2013, p. 55), or positioned in situations wherein mind and body are dissociated (Fenyvesi et al., 2020), self and collective efficacy enacted through playful collaboration in my research encouraged the teachers' understanding of the connective potential of STEAM and the power of experiential learning. Across the cases, *experiential* learning was re-framed as STEAM-derived practice, and the *experience* of learning was acknowledged as playful, productive persistence. Such elements support the literature (Dewey, 1938; Napier, 2010; Roberts, 2012), that highlights the influence of both erlebnis *and* erfahrung on teachers operating in STEAM learning contexts. The transition from fear to fearlessness presented in section 4.4.12, contributes to the body of knowledge regarding the role of dialectical emotions and their impact on collective teacher identity. This accords with views held by Boaler and Dweck (2016), Donohoo (2017), and Hattie (2017), regarding teachers' affective states, including feelings of anxiety or excitement, as one of the four significant sources of efficacy. Accordingly, the agreed risks taken by teachers in this study influenced their collective efficacy overall, leading to transformed perceptions of capability or competence at both organisational and individual levels (see 4.4.6). Even the behaviour of so-called 'resistant' teachers in STEAM 2 (see 4.3.7), on closer examination, revealed a small of teacher transformation *did* occur (see 4.5.1 and Table 4.1). This finding supports views held by Dweck (2008) claiming that growth mindset capabilities can be cultivated.

5.2.2 The value of ESM to STEAM research analysis

In my research, experience sampling was primarily used in the initial STEAM PL sessions in which the scope of the STEAM projects was introduced. It is important to reiterate that seven STEAM projects were developed for inclusion, each unique to this study (see tables 3.1 – 3.4). ESM was also applied during STEAM hand-making activities. These situations required teacher participants to record their feelings, thoughts and actions 'in-the-moment' (erlebnis) or close to its occurrence. According to Zirkel, Garcia and Murphy (2015), experience sampling methodologies (ESM) "have not been widely harnessed in education research" (p. 7), however have emerged in a small number of contexts related to education innovation (Csíkszentmihályí, 1990; Meyer & Turner, 2006), wherein aspects of this study are positioned. Zirkel et al. place ESM in the phenomenological tradition that focuses on subjective experience. Accordingly, ESM conducted in this study measured teachers' subjective responses within the context of human emotions experienced during instances of learning in STEAM. This provided a subtle difference to Zirkel et al.'s view, in that a phenomenographic approach, found teachers were responding to the understanding of the STEAM phenomenon through personal, unfiltered retrospection, shaped by emotions and not by knowledge content.

The value of ESM in this research is that the teachers' experiences were provided within a framework of *challenge* inside the context of STEAM, rendering the measurement of data as episodic, rather than semantic. Aligned with previous studies confirming that self-reporting 'right now' data and reconstructed semantic reflection are equally valid (Christensen, Barrett, Bliss-Moreau, Lebo, & Kaschub, 2003), the episodic provision of teachers' erlebnis reflections were later reinforced by more reflective interview data and observation. However, the serendipitous 'think aloud' moments, as Han and Ellis (2019) put it, during the hand-making of STEAM artefacts, defends the phenomenographic framework supporting this research (see 4.4.1). The inclusion of unsolicited self-reporting moments in the research analysis was crucial to the examination of teacher transformation and the effect of such on the teachers' sense of identity.

A common factor across the cases in which ESM was applied showed how maths-making activities prompted a range of emotions not limited to the teaching profession alone. Working through what Kahneman (2011) terms 'cognitive strain' towards 'cognitive ease' demonstrated how the unity between teachers' knowns and unknowns was articulated through robust expressions of curiosity (see Figure 4.28 – 4.30). These were interpreted as a largely human response over pedagogical. It must be noted, however, that Kahneman's (2011) view of the biological effect of mood on learning, contributed to the teachers' sense of success in the maths-making activities, supporting the literature related to STEAM's creative potential, and creativity in education in general (Burnard & Colucci-Gray, 2020; Keane & Keane, 2016; Taylor, 2016).

Experience sampling collected teachers' emotional responses to STEAM as it happened, and might be considered informal if not for the support it gave the research data ongoingly collected by other methods. The unexpected serendipity related to a feeling of surprise about a new task, or being curious, confused or frustrated (see 4.4.7), triggered a range of teacher responses that Pekrun (2014) calls epistemic emotions. Analogous to the delight experienced by solving cognitive problems, are 'haptic sensations', noted by Fiorilli et al. (2015) as feeling and mood. These shared teacher responses correlate with previous studies integrating social modelling and reinforcement in the development of creative learning ecologies (Bereczkia & Kárpátib, 2018; Ritchhart, 2015; Soh, 2017). In my research, the challenge, haptic sensations and epistemic emotions enabled teachers to develop and create a new STEAM culture of thinking. ESM may provide a valuable contribution to the way future STEAM education PL is designed as it presents immediate transformative responses – the fear to fearless journeys enacted through progressive erlebnis circumstances.

5.2.3 The impact of the quiet thrill of teacher achievement in STEAM

The quiet thrill of achievement influenced the teachers' personal and professional identity development by the acknowledgement of renewed capacities via STEAM learning. Section 4.5.1 demonstrated how the teachers' quiet thrill sprang from what Pallasmaa (2009) observes as the "faculty for sensing and discerning similarities across all domains of an individual's empirical emotional and intellectual experience" (p. 72).

In the same way, teachers who challenged themselves intellectually during participation in STEAM (see 4.4.15), further support Gardiner's (2016) claim that expanding neural pathways leads to an increase in the brain's ability to find new patterns and to manage more complex and challenging future problems. Apart from new thought processes, the teachers in this study admitted that incorporating arts related skills to explore STEM concepts required a lot of time to set up and deliver. However, the teachers also acknowledged that STEAM was a wise investment of time if they were benefit from what Sousa and Pilecki (2013) propose is "the value of sentient thinking functions". In relation to both research questions, thinking functions included play, curiosity, passion, fearlessness and purpose.

The experience of emotional states in STEAM teacher PL in this research – frustration, anger, fear, joy, pride – reframed the teachers' initial uncertainty as influential to the development of a preferred successful outcome. This is referred to in the literature as inertia to activism (Burnard et al., 2018). Creative thinking necessary for successful STEAM outcomes in this study eluded to a certain state that Koestler (1967) calls *promisingness*, where "creative activity is a type of learning process where teacher and pupil are one" (p. 23). Certainly, enabling teachers' growth mindsets during STEAM PL found the evolution of teacher uncertainty into promisingness, as well as confirming a form of tacit knowledge considered by Paavola et. al (2004) as "an essential resource for creative experts" (p. 10). Contextualising tacit knowledge in the teachers' STEAM learning, wedded the symbolic, theoretical nature of understanding, with the physical, embodied, experiential nature of the STEAM experience itself, which is directly aligned with Wagner's (2012) advocacy of play:

> So it would seem that the element of play is every bit as important in adults' learning as it is in how children learn. Play, then, may be an element of passion and purpose, as well as an intrinsic motivation that stands by itself. (Wagner, 2012, p. 30)

Play was essential to the action of 'making' for the participating teachers. Consistent with the literature, the effect and potential contribution of emotional and aesthetic factors to the teachers' self-perception and learning in this study, demonstrates convincing links between creative cognition and the neurobiological basis of *making* (Gulliksen, 2016; Pallasmaa, 2009). Making also generated teacher curiosity and fearlessness, expressed through sensations, feelings, passions and reactions (see 4.4.2)

These reactions provided evidence of teachers' physical *and* emotional commitment to STEAM learning as the study progressed.

Generally in STEAM PL undertaken in this research, at least one in five knowledge areas contributing to the learning was assumed to be new for collaborating teachers. This rendered the situation ripe for divergent thinking. McAuliffe (2016) suggests increasing divergent thinking to encourage collaboration is key to validating the activity emotions felt during learning something new. In this research, divergent thinking in the teachers' STEAM learning was apparent through the utilisation of design thinking methods, and problem solving, to transform STEM concepts into aesthetic form. Section 4.4.3 shows how the teachers' divergent thinking also aligns with the notion of 'playing around with ideas' (C. Campbell & Jobling, 2012; Craft, 2015). Divergent thinking was interpreted as teacher insights resulting from the collation of knowledge *and* experience through erlebnis, or the 'aha moments' (Kolb, 1984; Napier, 2010; Roberts, 2012) inherent in STEAM learning. Aha moments presented in section 4.4.1 were accompanied by powerful emotions (teachers *and* students), describing what Napier (2010) proposes as moments when "suddenly what was a tangle of confusion becomes clear and understood" (Napier, 2010, p. 1). Such understandings were made possible in the research through teacher collaboration and the desire to collectively own the STEAM learning. Hence, STEAM's aforementioned wicked problems were addressed through the contribution of differing expertise.

The disruptive nature of STEAM, or the 'wicked problem' posed by the requirements of authentic transcisciplinarity, required participating teachers to build innovation attributes into renewed pedagogy, and seriously consider themselves as bricoleur, as Campbell (2018) puts it. Teacher 6 in STEAM 1 presented evidence of the "inquiring, intellectually demanding and powerful" (L. Campbell, 2018, p. 5) influence of pedagogical bricolage. Teacher 6 was representative of how STEAM teachers often assume the role of 'change agent' in schools and communities (see Table 4.2): In the phenomenographic sense, the participating teachers experienced small and large transformations over time, and while these are key findings in the research, the transformations were mostly overlooked by the teachers themselves. What Dweck (2008) calls *becoming*, and Greene (2018) considers *a sense of incompletion*, the teacher transformations regularly observed in this study are further aligned with Napier's (2010) view of 'aha' moments. These were the moments exhibiting teachers' flashes of discovery, primarily associated with making STEAM artefacts with one's hands.

The emotional and intellectual stimulation provided by teachers' differing views and behaviour was crucial to enacting creative visible thinking in STEAM learning. Such thinking enabled the realisation of aesthetic forms that represented the STEM concepts investigated in each STEAM activity. Appropriately titled 'maths-making', ideation for the development of each STEAM artefact included in the study evolved from one or more fundamental mathematical theories, aligned with technology or skill associated with design and artmaking. These results of teachers' maths-making reflect those of Fenyvesi et al. (2020) whose studies of Maths in Motion (MiM) found transdisciplinary learning success was based in haptic sensations, embodiment and connection. Similarly, the forms of connection that emerged in this study (content, peers, school community), confirm what Patton and Knochel (2017) suggest, are vital to developing meaningful making "by investigating, interrogating, and reinventing" (p. 42). The need for balanced investigation of one or more STEM concepts through an arts perspective was dependent on the actions of *all* emerging teacher traits: *neat-freak, bull at a gate, formula maker, nervous perfectionist, panicker, resister,* and *edupreneur*. Reinvention depended on teachers' curiosity rising within professional learning activities where strong positive *and* negative emotions prevailed. As the literature suggests, curiosity in a teacher, is the product of one who is dedicated to their work, who is proud of what they do and who they are (Dweck, 2008; Hattie, 2012; Kahneman, 2011). "Someone who thinks carefully and does things well" (Berger, 2003, p. 1).

STEAM learning in this study also warranted the teachers' release of self, calling instead for bold collegiality in the way the learning was shared. Findings in section 4.3.8 demonstrated teachers were emotionally motivated by STEAM collaboration, expressing the desire to broadcast their learning beyond the confines of their school (see 4.3.8, 4.5.3). The intensity of teacher emotions within instances where STEAM learning was shared with external audiences, highlighted how altruistic joy contributed to the personal joy in achievement. The teachers' joy was particularly evident in activities that involved audience interaction or presenting the connections between the creation of unique physical artefacts and theoretical learning (see sections 4.4.2, 4.4.9, 4.5.3). Additionally, public exhibition of student work is one of the key features of

Project Based Learning (PBL) and inquiry. Seen primarily as an avenue for broadcasting student learning, my research shows how the exhibition of STEAM learning, internal *and* external to school settings engendered many proud and joyful situations for the teachers as well. These were the emotion-filled instances within which STEAM was experienced in Goleman's (2006) view, as a "quiet thrill" of achievement (p. 267).

Teacher individualism surrendered to newfound confidence in peer-to-peer learning in this research, further demonstrating how teachers' fearlessness and sense of collective purpose proved instrumental to personal and professional enhancement. This result was fundamentally stimulated by what Donohoo (2017) considers as gold-standard collective efficacy. The 'gold standard' was undeniably affected by the presence of teachers' emotions experienced during STEAM learning. Correspondingly, Keane (2019) situates STEAM teachers continually on the breach, using Wilson's (1999) Consilience Theory of how *everything connects*, to describe how the divergent study of relationships is informed by the convergent study of particulars (Keane & Keane, 2016). In my research, relationships were viewed from both content *and* human perspectives, and particulars were presented as nuanced specificity in the behaviours and knowledge that the teachers brought to the STEAM collaboration (see 4.5.2). This finding corroborates a great deal of the previous work in studies related to socio-cultural, phenomenographic approaches to teachers permitting themselves to play, fail, flow and feel (Craft, 2015; Csikszentmihalyi, 1996; Holdener, 2016; Marton, 1988; McAuliffe, 2016; Palmer, 1998; Robinson, 2010). Such permissions highlight the influence of transdisciplinarity on a teacher's sense of identity in the midst of current pedagogical and education complexities.

Understandably, those teachers who shared their students' STEAM learning journey in the public domain (see 4.5 3), experienced emotions of pride and joy, knowing that the STEAM journey they travelled themselves was also on display. The collective STEAM experience for these teachers in particular, aligns with Palmer's interpretation of emotions in teaching, as challenges that "enlarge our thinking, our identity, our lives – the fear that lets us know we are on the brink of real learning" (Palmer, 1998, p. 39). Similar sentiment is offered by Timm, Mosquera, and Stobäus (2016), who propose "the teachers' work is a state of risk of permanent imbalance. If in a steady state, stagnancy would result in identity and flow to be harmed" (p. 3). Certainly, there was no harm in tapping into teachers' emotions during the STEAM learning. This research showed that emotions are powerful contributors to developing a teacher bricolage focussed on what Tomlin (2018) and Santone (2019) propose are 22nd Century Cs; care, connection, community and culture. In consequence, emotions provided valuable augment to current 21st Century Cs intrinsic to STEAM – collaboration, communication, critical thinking, and creativit(ies) (Burnard & Colucci-Gray, 2020), and have the potential to enhance a teacher's sense of professional and personal identity development.

5.3 Chapter Conclusion

This chapter examined the epistemological strength of the research findings in relation to existing research in STEAM professional learning. The research aimed to elucidate how STEAM education activities might be co-designed and delivered to encourage teachers to explore other ways of viewing themselves, as well as relate the implications of teachers' experiencing activity emotions during STEAM learning. Key findings discussed in this chapter demonstrate how STEAM learning has transformative capacity for teachers, in that STEAM's transdisciplinary structure provides a gateway for innovative, connected thinking. Further results from the research find that operating outside pedagogical comfort zones encounters a range of teacher 'traits' to be aware of when designing challenging STEAM PL. Importantly, this research found that the display of dialectical emotions experienced in STEAM learning enhances teacher capabilities, and that ESM is a valuable mechanism to recording such emotions.

The purpose of this chapter was to present key findings that determine how stories from the teacher participants add to current and future innovative education settings, described by Tait and Faulkner (2016) as *edupreneurial*. The teacher narratives presented a range of instances related to innovative learning via enthusiastic and exciting exchange of ideas through STEAM. Such exchanges have been noted by Keane (2019) as how *everything connects*, and in this study as how *nothing is isolated*, demonstrating how emergent themes in the research align with transdisciplinary theory and intersect with literature related to specific focus areas of play, curiosity, passion, fearlessness and purpose (see Figure 4.2).

The research questions drew a response considering how to work in a transdisciplinary way, referred to in the literature as "avoiding artificial combinations (or separations) of subject disciplines” (Braund & Reiss, 2019, p. 10). Regarding STEM explorations through the Arts perspective, the existential truth is that the connections have simply always been, and it is the responsibility of STEAM educators to encourage self, peer and student awareness of such connections if we are to grow 21st and 22nd century skills across the field. May (1975) and Wagner (2012) recommend that teachers first must dive into the deep end of not-knowing. This was demonstrated in the discussion of research findings that contributed to the narrative inquiry intrinsic to this study. Taken together, the narrative demonstrated how the STEAM case study milieus were pedagogically challenging for the teachers, and how activity emotions exhibited by the teacher participants, in-service and pre-service, wavered between enthusiastic collegial excitement and perceived resistance. Productive persistence demonstrated by the teachers facilitating the STEAM programs, proved to be the most energetic and transformative element in the collaborations. This was evidenced by teachers’ constant and consistent peer-to-peer encouragement, confirming Hattie’s (2012) view of teachers’ demonstration of apparent care and commitment to peers, reminds us that we are all learners and we are all human.

The discussion presented in this chapter included claims related to the enhancement of teachers’ professional and personal identity through enacting transdisciplinarity, acknowledging the influence of activity emotions on learning, and establishing connected cultures of thinking through STEAM PL. While the results of this study vary between evidence of teachers’ enthusiastic willingness to maintain STEAM learning into the future, and teachers’ simple, one-time participation in a moment of STEAM challenge, the enduring quality of the STEAM learning experiences themselves signify the implications of the research. These are presented in the next chapter to conclude the study, with recommendations for next steps in relation to STEAM education research.

Chapter Six

Research Conclusion

> *When we have unified enough certain knowledge, we will understand who we are and why we are here. (Wilson, 1999, p. 7)*

Key findings presented and discussed in Chapters 4 and 5 demonstrated how STEAM learning has transformative capacity for teachers. Chapter 5 also examined the influence of activity emotions on teachers' learning, while discovering and establishing connected cultures of thinking through STEAM PL. Fundamental to these results was the acknowledgement of a range of teacher traits expected to be encountered when designing STEAM PL with pedagogical challenge in mind. These are the teachers who are unfamiliar with transdisciplinary learning, yet this study shows how each contributed value to the shared STEAM experience due to a willingness to risk traversing perceived knowledge boundaries, even if the crossing might fail.

This study has found that generally, variations in the teachers' shared emotions ranged from frustration to elation. However, newly formed collegialities offered familiarity, allowing most STEAM team members to experience a dynamic emotional range through PL *without* judgement. Diversity, dynamism and compassion presented by the teachers in each STEAM case equated to membership of powerful and collaborative working environments, including endorsement from professional associations, increased integration with professional networks, and alignment with sustainable innovative leadership. Valuing teacher difference, content connection, and unique methods of delivery, usurped the assumption that STEAM must align with data driven standardisation. It is important to recall, however, that the teachers' transformative stories recorded in this study, cycled through the observation and recognition of teacher traits that were not typical of knowledge specificity, but rather, were intrinsically human: the *neat freak*, *bull at a gate*, *formula maker, nervous perfectionist, panicker, resister, saboteur*, and *edupreneur*. Operating collaboratively, each type of teacher offered the subtle signs we must look out for as educators when developing or co-creating STEAM PL. Overall, the experiences collected and analysed in this research revealed fewer substantial and more subtle, nuanced changes in the behaviours of the participating teachers, particularly in the teachers' sense of self, as attitudes to challenging STEAM tasks and activities shifted and changed. Aligned with the literature, it was the small, self-effacing transformations expressed by the participating teachers themselves, that indicated the action of 'becoming', so prized by the work of researchers in the field of education transformation. In response to the research questions underpinning this study, STEAM learning pushed the teachers to the edge of their pedagogical comfort zones, resulting in personal and professional growth, albeit for a short time.

6.1 Research implications –

6.1.1 STEAM expands fields of view in teacher professional learning

Overall, this study has indicated that there are many extraordinary STEAM teachers present in what might be considered ordinary secondary school settings, and that given the right resources and opportunities, such teachers will find and work with each other to shine brightly. Small, and possibly invisible teacher transformations offer potential for large impacts when considering the implications of designing challenging STEAM PL. Interpreting teachers' STEAM experiences through three literature perspectives: transdisciplinarity, activity emotions, and commonalities of practice, allowed the study to emerge as a critical analysis of connections; theoretical, pedagogical and social. The triple perspective aimed to un-silo specific learning entities, with a view to exploring the interconnected conduits to measuring shifts in teacher mindset during the development and delivery of STEAM PL, and subsequent implementation of STEAM education programs in schools. The STEAM environment or situation within which teacher agency was shaped, encompassed a range of human emotional factors occuring at a particular time, in a particular instance. Such temporality aptly positioned the study within the domain of phenomenography and unavoidably included the impact of emotions on the teachers' experience. The triple perspective also drew on notions of teacher identity and agency, indicating how challenging oneself beyond regular comfort zones resulted in transformed teacher self-perception. This provides compelling reasons for encouraging transdisciplinary STEAM education in a range of learning contexts.

The credibility of this research is upheld by the small percentage of participating teachers who have expanded their field of view and influenced the views of others, which is testament to the teachers' grit skills and indicative of the potentiality of STEAM learning. In light of this fact, realising idealistic models of learning to broaden teachers' content knowledge and integration strategies, while honourable, must be tempered with the current neo-liberalist sociocultural properties of the profession, including the degrees of anxiety forming within an already overwhelmed community of educators. Triangulation applied in this study, in terms of research methods and the range of participants, suggested that assuaging teacher resistance to STEAM takes many forms, but has one unifying human element for the researcher and researched both; that is, productive persistence, or grit. The teachers' grit and persistence required effort, and there was an emotional value inherent in effort. Hence the contribution of substantial epistemic emotion recorded during the STEAM learning activities, affording appropriate analysis in response to the research questions. *The Value of 'Me' in STEAM* was, and continues to be, a human enquiry, with implications for all teachers participating in challenging PL.

It must be acknowledged that the study of teacher transformation through STEAM learning, however miniscule or magnificent, is dependent on building rapport between the STEAM 'experts' and 'novices'. In this way, designing challenging STEAM PL will affect the way teachers self-identify, affording them an expanded field of personal and pedagogical view. In this study, narrating such shifts in identity demonstrated the complexity of combined constructivist and phenomenographic frameworks enveloping the research, and pointed to the dense overlapping nature of personal experience with professional environment. Shenton (2004) says "participants should be encouraged to be frank from the outset of each [data collection] session" (p. 66). Regarding the research question: How can STEAM education activities be co-designed and delivered to encourage teachers to explore other ways of viewing themselves?, Teacher 6 from STEAM 1 articulated a response that is central to my inquiry:

> I look in the mirror now, and I don't recognise the old me. I see that new person, "STEAM leader - Innovation expert", and I say to myself "who are you" and "how did I get here"… but here I am. It's great! Bring on professional development and teaching growth!

Serving as a poster-child for the aims of this study, S1T6 represented the axiological positioning of my research, making it possible to conclude that for teachers learning in STEAM, the 'quiet thrill' of achievement, as Goleman (2006) puts it, can indeed, be identity shifting. To develop a full picture of the value of STEAM for non-generalist teachers, additional studies will be needed to ascertain how authentic transdisciplinary STEAM encourages teachers to view their own knowledge through different lenses, potentially viewing themselves in alternative ways. This study, however, indicated how a treasury of unique STEAM ideas put into practice can be personally and professionally transformative for teachers, even if only for the duration of the STEAM practice.

6.1.2 STEAM provides teachers the permission to play and risk

The implications for teacher professional learning are influenced by the analysis of teacher responses to STEAM undertaken here, and how such responses contribute to the potential extension and value of transdisciplinarity through playful, curious and fearless enactment of STEAM learning. This study demonstrated the importance of promoting and explaining how fears related to a STEAM learning trajectory were overcome, in order to create a unique, playful and positive learning experience for the students and teachers alike. The acknowledgement of the teacher traits, and interpretation of the behavioural range anticipated or expressed by teachers exhibiting such traits in this research, is relevant for education researchers designing novel transdisciplinary STEAM PL. Permission to play in secondary teacher PL required strategic inputs from both PL designers and participants. In relation to STEAM, it is necessary to embrace risk, encourage new ways of thinking through 'making', and seek peer critique and support within collaborative settings based on established collective goals. Engagement with risk is important if only for the experience of doing something new, different, or for the establishment of new ways embracing change and constructing knowledge. My research shows that in STEAM, teachers making things by hand is as important as playing around with ideas. A major implication is that engaging with the sense of touch to realise conceptual STEAM understandings affects teachers' individual and collective mood *and* influences environmental atmosphere.

This study showed how playfully constructed STEAM PL provided teachers with multisensory, omnidirectional and embodied encounters that moved learning to a new level. The implication here is that encouraging peer review of STEAM's playfulness has the capacity to broaden collaborative teacher relationships, benefitting *all* players. Furthermore, encouraging teachers to share how they have played in STEAM, exposed the combination of generative thought and physical making to peers, the wider school community, and external audiences. Seeking feedback related to the experience of transdisciplinarity in STEAM, fosters further practice of divergent thinking in education, creating a learning environment where teachers are open to challenge that nurtures growth mindsets. Permission to play, for teachers, demands courage and risk.

Risk was not a solo entity in the STEAM learning undertaken by the participating teachers. Comparison of the findings with those of other studies confirmed that spending some time identifying like-minded risk-takers in an education environment revealed synchronicity in teacher intention and purpose. This was exemplified across the cases, and explicitly in the case of STEAM 1, in which the teachers collectively agreed: "*We are going to run with this even if it fails".* It didn't. The fearlessness evident in such intentions implies that teachers' perceptions appeared unconscious or secondary to rational thought, exemplifying new understanding that teacher emotionality has genuine value in setting collective goals for STEAM success. This is a factor to be considered in the design of transdisciplinary STEAM PL.

6.1.3 STEAM PL asks teachers to make connections and unify learning

This study has confirmed the presence of risk in STEAM learning, risk that aims to avoid replacement or belittlement of subject specific content, particularly in maths and science, the areas of learning where social and economic commitment to improved knowledge is widely broadcast. Here, teachers were required to consider how exposing deep differences between subject disciplines served to cultivate divergent thinking, particularly when investigating connections between seemingly disparate knowledge areas. McAuliffe (2016) views the greatest risk to such cultivation is that "one area will be paid lip service, counted as being covered, but in fact not honoured" (p. 8). Correspondingly, this study did not propose to denigrate the wealth of skills in traditional ways of learning and teaching, or to undermine the value of *slow* artmaking such as drawing and painting. Rather, the study attempted, and achieved, the integration of those traditional *making* skills with ostensibly 'cerebral' content, in order to track the acknowledgement of intersections and their contribution to the teachers' learning experiences.

The overarching unifying element for the teachers in this research, was *connection*. The implication of such on the continued design of STEAM teacher PL is that authentic and relevant connection is crucial to the STEAM learning experience. The insights gained from this study have extended the understanding of how teachers' discovery moments, experienced through playful and curious pedagogical methods, afforded a greater sense of connection. By connection, I refer to connected people, teaching and learning concepts and content, creative capacity, and teachers' curiosity and willingness to play. My study adds to the growing body of research that indicates how the discussion of balanced content contribution, arbitrated by diverse thinking styles, encourages teachers' connected field of view. Including those categorised as generalists, it was clear that teachers who stepped outside their area of expertise in order to collaborate and work towards a connected STEAM outcome, experienced moments of discomfort in the face of perceived *not knowing* content or skill specific to the task. However, the interrelatedness of discipline and experience embodied in how the teachers know what they know, think as they think, feel as they feel, and be who they are, demonstrated how genuine STEAM transdisciplinarity can be successfully achieved by negotiating teacher difference openly through listening, respect, empathy and self-reflexivity.

This approach taken in this research will prove useful in expanding our understanding of how teachers build innovative knowledge communities, flourishing through purposeful critical thinking. My study has raised questions about the connective value of STEAM in relation to student and teacher transdisciplinary learning, in situations where STEAM learning experiences were perceived by both as too challenging or chaotic. Certain creative chaos accompanied the STEAM inquiries within this research, apparent in the actions and emotions of the teachers as well as students. Simultaneously, individual moments of flow were observed where teachers benefited from learning through connections between traditional *and* innovative methods of delivery. For the teachers, STEAM included processes of ambiguity and transformation, surprise and frustration, experienced through tacit knowledge building, and inherent in pushing personal learning boundaries. The results of my research add to the exciting developments in transdisciplinary education, finding teachers' emotional states such as fear, trepidation, frustration, perseverance, and even embarrassment, intrinsically important to creating connected cultures of thinking in schools.

6.1.4 Authentic STEAM is not 'box ticking'

Implications for further research are related to both identifying the importance of linking discipline concepts and skills in transdisciplinarity, *and* how connecting fields of knowledge across disciplines must have real-world application. This study has gone some way towards enhancing the understanding of how teachers participating in STEAM increase their capacity for connectedness in all aforementioned forms. Of particular interest was the way teachers worked towards generating innovative pedagogical strategies in order to create and manage sustainable STEAM programs in their schools. Each strategy was underpinned by integrated STEAM concepts, contexts and creative technologies in order to establish whether the STEAM experience was individually and/or collectively beneficial, or simply an action of box ticking. The research outcome permits me to conclude that there was definitely a measure of both, and is to be considered in further research related to designing authentic STEAM teacher PL. While most teacher participants were not simply *ticking boxes*, neither was the representation of STEM and Arts conclusively balanced in all programs co-created for the study. Extending the life of the STEAM programs or projects would require a more rigorous understanding of transdisciplinarity in comparison with interdisciplinarity and multi-disciplinarity. The striking effect of participation in STEAM 1 and 3, in particular, was the way teachers *did* display increased understanding of the contribution of content balance that determined the value and validity of positioning STEAM in an authentic transdisciplinary learning arena.

Implications for designing authentic STEAM PL in respect of real-world application are dependent on teachers collaboratively shaping STEAM learning experiences through concept and skill interrelatedness. STEM to STEAM education is in much danger of becoming pedagogically redundant if there is little 'real-world' application, critically identified in national curriculum documents. For example, numeracy, a mandated *general capability* across all Australian Curriculum (AC) areas, is also emphasised through the cross-curriculum priorities set out in the same document. More specifically, an example from AC Mathematics curriculum states "In *Measurement and Geometry*, there is an opportunity to apply understanding to design" (ACARA, 2014e, p. 30). It is appropriate to concede that rigid theoretical maths and science content cannot be taught through the Arts, yet this study showed that concepts from maths and science, in fact, all STEM knowledge areas, can be fearlessly connected with the Arts and Design knowledge and learning areas. Such was the teacher's intention in developing authentic transdisciplinary STEAM learning undertaken in this research.

6.2 Research rigour and limitations

Hybridising phenomenography with constructivism was a valuable interpretivist approach to this research. The teachers' learning experiences were deeply grounded in phenomenography, which aptly supported the socio-constructivist framework, in that phenomenography does not separate the individual from the experience. During data collection, analysis and synthesis, supervisory feedback and discussion of the data with peers was crucial to how the research narrative unfolded. Still, the greatest methodological implication related to researching the effect of STEAM on teachers' professional and personal learning, is to resist bias in observational data analysis.

All elements of a transformative fear-to-fearlessness journey were acknowledged in characteristics of the teachers identified in the study, which further indicated the pitfalls of interpretation based on observation alone. By that, I mean avoiding misinterpretation of teachers' behaviour as 'resistant' when in fact, given time for additional data collection and analytical reflection, the behaviour was actually engaged. Hence, triangulation, in the use of different methods including individual interviews and group reflections, supported by the collection of immediate in-the-moment responses gathered through experience sampling methods (ESM), provided credibility in terms of acknowledging the expansion of the teacher participants' transformed professional or personal view of themselves. Triangulation across four sites of data source also provided diversity of experience and perspective within similar points in time. According to Shenton (2004) triangulation affords verification of individual viewpoints and experiences in relation to the attitudes and behaviours of a range of others, ultimately providing a 'rich picture' of those under scrutiny. With the idea of painting a 'rich picture' in mind, this study was designed to be conducted across different locations, including a range of teacher participants with expertise in various content knowledge. I have tried to credit each participant with their own voice in the findings, even in the event of analysing individual *behaviour* over actual words. In this way, it is possible to acknowledge transferability of many aspects of this research to alternative contexts, primarily focused on PL within schools eager to innovate in the area of transdisciplinarity. Despite this, limitations to the study surfaced in the size of the data set and the form of STEAM learning co-created for this research.

The first limitation was associated with the inclusion of data from STEAM 4, a case study conducted over two PL sessions delivered to members of a regional mathematics association. Generally, results in this case indicated positive teacher motivation and enthusiasm for the new and unique learning undertaken in their STEAM PL sessions. However, drawing conclusions as to whether or not the participating teachers applied the learning in their classrooms can only be speculative. While empirical evidence existed in relation to erlebnis (in-the-moment) STEAM experiences, it was impossible to gauge any longer-term effect on teachers' professional and personal identity in STEAM 4. This issue foregrounds the primary concern I have identified in terms of research limitations; the size of the data set.

While there was a greater number of educator participants in this study (58), there was a limited number included in my intensive focus (14). However, measuring the impact on the lives of those teachers was key to claiming the importance of STEAM learning in a generalised sense of evolved holistic pedagogy. Additional research would need to be conducted with larger groups of participants, over longer periods of time, to fully analyse how STEAM PL affords shifts in teacher identity in broader terms. Interestingly, broadcasting the success of the STEAM programs to external audiences in STEAM 1 and 3 in particular, increased the collective and individual efficacy of the participating teachers in those cases. This supported the field of view that considers the attributes of STEAM teachers being highly valued in whole school communities. Again, further research would need to be conducted to ascertain how this sense of value could be maintained for all teachers interested in embedding the Arts in STEM, and how the contributions of such teachers is measured against generalist or integrative methods of pedagogy already existing in the system.

Another major limitation is related to the STEAM learning co-created for this research. These programs and associated STEAM learning activities were not typical, even in the current STEM/STEAM education zeitgeist. They required substantial creative problem solving to uphold the highly creative level at which they were pitched. Most of the participating teachers rose to the challenge. However, perceived teacher resistance and fixed mindsets also prevailed. While unconstructive teacher responses and attitudes proved an impediment to collaboration, the emotional contagion of the STEAM activities demonstrated that enthusiasm of a handful of teachers was enough for the larger set to come on board. Even so, outlaw emotions such as fear, irritation and resistance were negated by productive persistence witnessed as positive collegial inveigling, and enacted through the display of activity emotions such as excitement, enthusiasm, joy, and achievement. Such emotions demonstrated sufficient evidence for teachers' responses to their STEAM learning to be classified as 'liminal' in the sense of liminality being dialectically troublesome *and* transformative. Future research of this kind must consider the level of uniqueness written into the design of STEAM teacher PL and whether a more 'typical' or less challenging method of STEAM learning would be more appropriate.

6.3 Future directions rising from the research

The present study investigated how STEAM professional learning (PL) encourages teachers to explore other ways of viewing themselves, and how such learning is impacted by the teachers' *felt* experiences. Such experiences were recorded and analysed using mixed methods within a case study methodology, drawing on features of narrative and appreciative inquiry. In response to the research questions, it was important to appreciate the dynamic contribution of emotions in the context of teachers pushing curriculum boundaries via STEAM, thus affording shifts in the teachers' self-identity to be identified. Several future directions for STEAM PL can be established from this study. Using ESM as a research method in STEAM teacher education lays the groundwork for powerful humanist knowledge building that eases teacher anxieties related to 'not knowing enough'. Recording teacher emotions via ESM has the potential to provide clear understanding of how the function of a relational system can be influenced by a range of unexpected interacting components. In this study, the interacting components were categorised through multiple creativities operating when teachers permit themselves to play, be curious, passionate, and fearless. Despite that, experience sampling enacted during the teachers' learning situations sometimes exposed creativity as a forced action. Such forced actions regularly led to critical thinking – compelling each teacher, or groups of teachers, to think through alternative aspects of the problem at hand, resulting in the teachers' discovery of spirited flows of creative and critical thinking and unexpected innovations in their approach to STEAM pedagogy. There is room for expanding an ESM approach to further teacher education research.

This study attempted to reinforce the wisdom inherent in connecting STEM and the Arts through the development of innovative pedagogy for a variety of subject specific teachers. The analysis of teacher emotions undertaken during STEAM PL and related delivery of STEAM to students, has contributed to the body of knowledge that unites Vygotskyan theories of human development with the integration of emotion in motivation, when conducting studies into how and why learners learn or want to learn. Building on such theories, this study includes assumptions related to cognition, motivation and emotion being inseparable co-contributors to a system of learning. For the participating teachers, such systems served to create affect, as indeed in all human lives, as we continually evolve our sense of professional and personal identity. Further research might explore how teachers place curiosity, fearlessness, passion, and play firmly within the swathe of attributes necessary for pushing curriculum boundaries via STEAM learning. Such attributes appropriately embody our current understanding of skills necessary for learning in the 21st century: communication, collaboration, creativity and critical thinking. Going forward, this study contributes to a growing body of knowledge anticipating education futuring from a further 22nd century skill set: care, connection, community and culture, which for transdisciplinary STEAM, is dependent on the active pursuit of STEAM teacher ownership with a view to sustainability.

In reference to participation in STEAM projects enhancing or detracting from a teacher's personal identity development, it can be concluded that developing confident transdisciplinary teacher 'traits' will be ongoingly recognised and valued as innovation enabling at any school. Therefore, valuing teacher difference, in terms of knowledge specificity, pedagogical behaviour, and personality traits, can be seen to augment a fluid integration of Arts and STEM, and should be expected when designing STEAM PL that is considered innovative and forward thinking. Supported by much of the literature, it is clear to state that teacher attributes of curiosity, passion and purpose must take on elements of fearlessness and willingness to play, for teachers to think innovatively and become edupreneurially agentic. While there are formidable challenges facing the wave of teachers committed to creating innovative learning experiences, particularly focused on STEM/STEAM integration, increasing the provision of opportunities to learn to innovate by using a range of creative systems and processes, will permit greater numbers of teachers to gain that sense of enablement that comes with high-perceived self-efficacy. Transdisciplinary STEAM PL programs offer such opportunities.

While the findings from the study cannot be generalised to represent the views or levels of engagement of *all* teachers attempting to collaborate in STEAM, they provide relevant insights into the pedagogical communication across curriculum areas in secondary school settings. The research analysis presented the discovery of views and perceptions that may be indicative of a broader education community view, however the research focus on such small individual cases rendered such generality impossible. Cross-curriculum priorities and general capabilities mandated through the Australian Curriculum (ACARA, 2014d) predict greater collaboration across disciplines. However, further research is needed to provide evidence of how teacher professional development and personal engagement with transdisciplinary STEAM programs might impact learning in secondary school with a view to addressing future STEM workforce needs.

The stories from teachers participating in this study raised questions about the evolution of STEAM programs at their schools, due to essential inputs being contingent to sustainability. Sustainability would be dependent on maintaining teacher STEAM skills, continual development of inter-disciplinary content knowledge, and active regeneration of the human collaborative elements of the STEAM programs. Contributing to the field of research related to STEAM education more broadly, which is critical for STEAM sustainability and associated teacher professional development in any school, is how we understand the importance of emotional connections related to learning outside one's comfort zone. In this study, it was important for participating teachers to push through the 'pain points' accompanying emotions in STEAM learning, suggesting that further research could usefully explore how outlaw and activity emotions are essential for growing transdisciplinary expertise. Many of the participating teachers have thrived in their newfound confidence to cross disciplines, push curriculum boundaries and create authentic transdisciplinary STEAM education experiences into the future. Further work needs to be done to establish whether similar STEAM PL can thrive in more locations across different education networks.

6.4 In conclusion

Considering liminality, teachers participating in this research can be metaphorically compared to the resources used in the paper engineering enacted in many of the STEAM projects. Reflecting Lumifold, Binary Bugs, and Hyperbolic Paraboloids, the action of transforming paper from a two dimensional to three-dimensional state, pertains to the action of choice. The type of technical folding applied in these projects revealed that paper has memory. Shape memory origami has been described as having only two states, fully open, or fully closed: hence the reference to choice. After folding and unfolding, a paper sheet can be easily re-formed into its new shape. It is for that reason that the metaphor exists between the teacher participants and the paper. The teachers held a memory of what they were before experiencing the STEAM programs, and a clear impression of what they have become now. Or rather how they *feel* now and what they *know* now. Continuing the paper folding metaphor, where folds alternate between terms 'mountain' or 'valley', an individual teacher might choose to ascend, building a mountain of connected knowledge, or choose to descend, digging deeper into valleys of connection, both directions constructed through integrated STEAM understanding. Some teachers may choose to return to an original flat state. The Hyperbolic Paraboloid pictured in the sequence of images in Figure 6.1 metaphorically represents the teachers' transformative journey through STEAM learning actioned throughout this research. The journey travels from a flat state to complex form, enacting divergence and convergence, continually expanding and contracting to exercising alternatives in pedagogical practices.

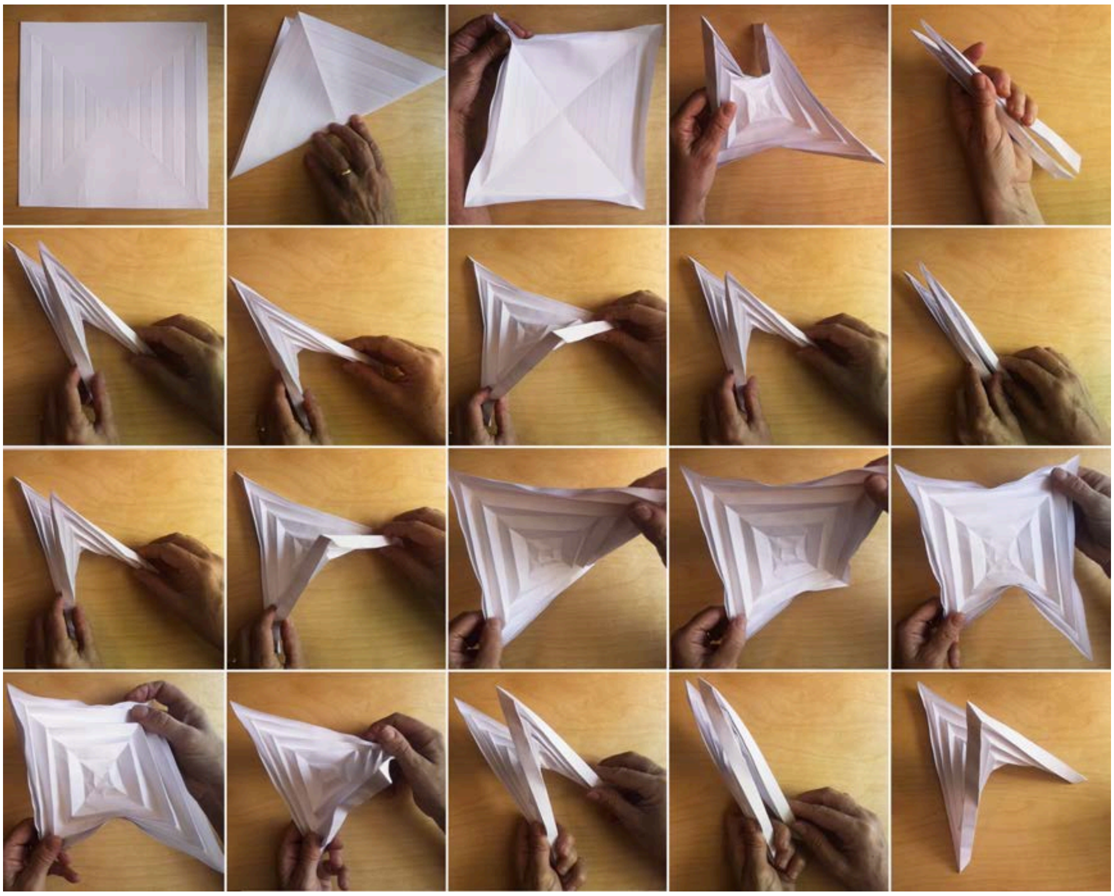


Figure 6.1: The creation and manipulation a model of a Hyperbolic Paraboloid.

When the participants in this STEAM research operated as individual entities, their experiences were personally transforming to a range of degrees. As is the case for the auxetic characteristics of the folded paper, when stretched, the teachers appeared larger. Yet it was when they operated collaboratively, that provided the greatest analogy to the paper engineered structures produced as STEAM artefacts in the learning programs. For the participating teachers, STEAM affordances led to learning experiences that were generative in their complexity and flexibility, in the same way as the folded paper. The analogy perfectly demonstrated persistence and achievement through adversity or resistance. It also demonstrated a metaphor for courageous encouragement and effort in the gentle hands of the teachers leading the STEAM programs co-created for this research. Such teachers are the multi-dimensional change-makers required for STEAM education futures.

Appendix A

UTS Ethics Approval – HREC reference no. ETH17-1213

Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "The Value of Me in STEAM". Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. ETH17-1213.

Approval will be for a period of five (5) years from the date of this correspondence subject to the provision of annual reports.

Your approval number must be included in all participant material and advertisements. Any advertisements on the UTS Staff Connect without an approval number will be removed.

Please note that the ethical conduct of research is an on-going process. The National Statement on Ethical Conduct in Research Involving Humans requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually from the date of approval, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

You should consider this your official letter of approval. If you require a hardcopy please contact Research.Ethics@uts.edu.au.

To access this application, please follow the URLs below:
* if accessing within the UTS network: https://rm.uts.edu.au
* if accessing outside of UTS network: https://vpn.uts.edu.au , and click on " RM6 – Production " after logging in.

We value your feedback on the online ethics process. If you would like to provide feedback please go to: http://surveys.uts.edu.au/surveys/onlineethics/index.cfm

If you have any queries about your ethics approval, or require any amendments to your research in the future, please do not hesitate to contact Research.Ethics@uts.edu.au.

Yours sincerely,

Associate Professor Beata Bajorek
Chairperson
UTS Human Research Ethics Committee
C/- Research & Innovation Office
University of Technology, Sydney
E: Research.Ethics@uts.edu.au

Appendix B

Ethics Approval – SERAP reference no. 2017083

Education
Public Schools

Ms Melissa Silk
[redacted]

DOC17/796557
SERAP 2017083

Dear Ms Silk

I refer to your application to conduct a research project in NSW government schools entitled *The Value of Me in STEAM*. I am pleased to inform you that your application has been approved.

You may contact principals of the nominated schools to seek their participation. **You should include a copy of this letter with the documents you send to principals.**

This approval will remain valid until 27-Jul-2018.

The following researchers or research assistants have fulfilled the Working with Children screening requirements to interact with or observe children for the purposes of this research for the period indicated:

Researcher name	WWCC	WWCC expires
Melissa Silk	WWC0593474E	05-Feb-2020

I draw your attention to the following requirements for all researchers in NSW government schools:

- The privacy of participants is to be protected as per the NSW Privacy and Personal Information Protection Act 1998.
- School principals have the right to withdraw the school from the study at any time. The approval of the principal for the specific method of gathering information must also be sought.
- The privacy of the school and the students is to be protected.
- The participation of teachers and students must be voluntary and must be at the school's convenience.
- Any proposal to publish the outcomes of the study should be discussed with the research approvals officer before publication proceeds.
- All conditions attached to the approval must be complied with.

When your study is completed please email your report to: serap@det.nsw.edu.au
You may also be asked to present on the findings of your research.

I wish you every success with your research.

Yours sincerely

Production Note:

Signature removed
prior to publication.

Dr Robert Stevens
Manager, Research
27 July 2017

School Policy and Information Management
NSW Department of Education
Level 1, 1 Oxford Street, Darlinghurst NSW 2010 – Locked Bag 53, Darlinghurst NSW 1300
Telephone: 02 9244 5060 – Email: serap@det.nsw.edu.au

Appendix C

Sample Consent Forms

PARTICIPATING SCHOOL CONSENT
THE VALUE OF ME IN STEAM
UTS HREC ETH17-1213

I ___________________________ agree to ___________________________ to participate in the research project "The Value of Me in STEAM" **UTS HREC ETH17-1213** being conducted by Melissa Silk, doctoral student at UTS. Melissa.Silk@uts.edu.au

I understand that the purpose of this study is to find out about the experience of engaging in STEAM activities in a range of learning experience settings. A STEAM project is one where an Arts approach is embedded within Science, Technology, Engineering and Mathematics concepts. The project being implemented here involves "making with mathematics". The research aims to investigate how emotions experienced during engagement in STEAM activities contribute to learning for all participants.

I understand that I have been asked to participate in this research because ___________________________ involvement demonstrates our interest in developing new ways of engaging in making with mathematics in order to explore the connections between Mathematics and the Arts more explicitly.

I understand that my participation in this research will involve informal interviews with students and teachers while undertaking the STEAM projects devised by the school and researcher in collaboration. Interview questions will be related to:

- The concepts being explored (Science, Technology, Engineering, the Arts and Maths)
- How the participant feels about exploring these concepts in new ways
- The emotions experienced during the making sessions related to the project
- Understandings and insights experienced during and after the project

I agree to:

• Photographic recording of students and teachers at work (non identifiable)	YES ☐	NO ☐
• Photographic recording of completed work/designs	YES ☐	NO ☐
• Audio recording of responses during interviews	YES ☐	NO ☐
• Use of interview responses in data collection	YES ☐	NO ☐
• Use of informal comments recorded during the workshop	YES ☐	NO ☐

I agree that the research data gathered from this project may be published in a form that:
☐ Does not identify participants in any way
☐ May be used for future research purposes

I am aware that I can contact Melissa Silk if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason and without prejudice to my relationship with the facilitators of the workshop or UTS.

____ ____/____/____
Name and Signature (Principal) Date

____ ____/____/____
Name and Signature (researcher) Date

NOTE:
This study has been approved by the University of Technology Sydney Human Research Ethics Committee (UTS HREC). If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au, and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

PARTICIPATING TEACHERS CONSENT
THE VALUE OF ME IN STEAM
UTS HREC ETH17-1213

I ____________________________ agree to participate in the research project "The Value of Me in STEAM" **UTS HREC ETH17-1213** being conducted by Melissa Silk, doctoral student at UTS. Melissa.Silk@uts.edu.au

I understand that the purpose of this study is to find out about the experience of engaging in STEAM activities in a range of learning experience settings. A STEAM project is one where an Arts approach is embedded within Science, Technology, Engineering and Mathematics concepts. The project being implemented here involves "making with mathematics". The research aims to investigate how emotions experienced during engagement in STEAM activities contribute to learning for all participants.

I understand that I have been asked to participate in this research because my involvement demonstrates my interest in developing new ways of engaging in making with mathematics in order to explore the connections between Mathematics and the Arts more explicitly.

I understand that my participation in this research will involve informal interviews while undertaking the STEAM projects devised by the researcher in collaboration with the school. This will include questions about aspects of the STEAM project related to:

- The concepts being explored (Science, Technology, Engineering, the Arts and Maths)
- How I feel about exploring these concepts in new ways
- The emotions I experience during the making sessions related to the project
- My understandings and insights experienced during and after the project
- My observation of student insights experienced during and after the project

I agree to:

• Photographic recording of me at work (non identifiable)	YES ☐	NO ☐
• Photographic recording of my assisting the students at work	YES ☐	NO ☐
• Audio recording of my responses during interviews	YES ☐	NO ☐
• Use of my interview responses in data collection	YES ☐	NO ☐
• Use of my informal comments recorded during the workshop	YES ☐	NO ☐

I agree that the research data gathered from this project may be published in a form that:
☐ Does not identify me in any way
☐ May be used for future research purposes

I am aware that I can contact Melissa Silk if I have any concerns about the research. I also understand that I am free to withdraw my participation from this research project at any time I wish, without consequences, and without giving a reason and without prejudice to my relationship with the facilitators of the workshop or UTS.

____ ____/____/____
Name and Signature (Teacher Participant) Date

____ ____/____/____
Name and Signature (researcher) Date

NOTE:
This study has been approved by the University of Technology Sydney Human Research Ethics Committee (UTS HREC). If you have any concerns or complaints about any aspect of the conduct of this research, please contact the Ethics Secretariat on ph.: +61 2 9514 2478 or email: Research.Ethics@uts.edu.au, and quote the UTS HREC reference number. Any matter raised will be treated confidentially, investigated and you will be informed of the outcome.

Appendix D
School Case Study Chronologies

The following narrative chronologies detail the trajectory of each STEAM Case Study, including related professional learning (PL). Complementing the STEAM process outlined in the previous section, the following chronologies detail "when" the STEAM projects were enacted, signifying the realisation of a *product*. Contextual to this research, *product* is defined as the output from four case study settings in which a range of STEAM PL occurred. Each case study is presented chronologically, supported by a timeline demonstrating the development and delivery process (see Figure 3.1). Consequently, time is employed as the mechanism through which differentiation and feasibility of the cases are presented.

Case Study 1: STEAM 1

2016 - November

Upon meeting personnel from School 1 late in 2016 by attending a range of professional conferences, initial discussions related to incorporating the A in STEM led to a STEAM model of learning being presented as part of a Project Based Learning (PBL) incentive as per the Buck Institute PBL model (see Figure A1.1). At that time, PBL was delivered within discrete subject areas such as mathematics and science. The Principal supported and encouraged S1T1 to consider an integrated STEM program with the inclusion of the Humanities in their cross-curricular exploration, tentatively titled '$STEM^{H}$', (STEM to the power of H). The superscript H, appearing as an index figure, represented the inclusion of a range of Humanities and Arts subjects, including visual and language arts, history, culture and society studies. Appropriately, the title evolved into STEAM with the understanding that the A would aim to incorporate said *Humanities* attributes.

Figure A1.1: Gold Standard PBL Model. Adapted from Buck Institute, PBL Blog (Larmer, Mergendoller, & Boss, 2015)

The integrated project proposed for School 1 was to be undertaken by the entire Year 7 cohort over a one-week period of collapsed timetable scheduled for delivery at the end of Term Two (late June) the following year. The program was to be presented as an immersive STEAM experience.

Referring to the 'public product' component of the PBL model (see Figure A1.1), School 1 was committed to finding an appropriate venue to showcase their STEAM learning in an external location. A relationship with a local corporate retail centre was mooted, later to become a feasible reality. Therefore, the STEAM PBL program developed into a strategic dual incentive:

- to collaborate and co-create a STEAM (PBL) program for delivery to School 1's Year 7 cohort, including PL for participating teachers in order to provide sustainable STEAM learning into the future.
- to produce a range of interactive artefacts for presentation and exhibition within a local corporate retail centre at the end of the program (public product).

Project Based Learning and the public product

Establishing a relationship with the local retail centre shifted the focus of the PBL guiding question. Using Design Thinking methodology with reference to community development values, a new guiding question was established in relation to the education initiatives from both School 1 and the retail centre: *How might we improve connections with people in our community?* Numerous learning opportunities were mooted under the new guiding question, promoting the action of *walking in another* *person's shoes* – empathy. The program aimed to find meaningful solutions that could be implemented and demonstrated to the public through a STEAM lens. Initial teacher planning involved approaching the STEAM program as a 'speculative journey' with many potential endings, creating understandings related to:

- a sense of place,
- who lives there
- who lived there before
- who might live there in the future
- what people need (age, gender, ability, language)
- what people like (fun, food…)
- Interactions
    - Built and natural environments
    - Intergenerational – students involved in the teaching

A full inventory of the STEAM options considering the guiding question, technological feasibility and professional expertise of the team members is located below. STEAM requires making, therefore, possible investigations of *making* projects emerged as:

- Mathematical flextangles (renamed as 'flextales' during School 1 second STEAM PBL iteration) incorporating stop motion animation to represent shared histories (see Figure 4.10).
- Maths concepts related to Lumifold activity (possibly linked with personal stories)
- Sensor activated soundscapes
- Paper circuits
- Augmented reality – hidden information (imagery/video/music) to demonstrate narratives
    - Who lives in your street?
    - What's behind the front door?
    - What's in your backyard
    - Digital documentation of the School 1 STEAM process and communication this to a wide audience
- Robotics to demonstrate how we might navigate our area in the future
    - Driverless vehicles
    - Resource distribution
- Maths and 3d printing to visualise words form different languages (public art value)
    - Incorporating software to record sound and sensors to play the sound of the language (makey makey)
- The interrelationships between groups

- Construction of a “marble race” to represent the family journey from country of origin to Australia
- Data collection and representation – related to natural & built environments and intergenerational information gathering – non verbal communication of quantitative data
- Music
- Birds in the district
- Rubbish
- Language groups
- Likes and dislikes
- And so on…

Professional Learning summary

Over three years, PL in STEAM 1 was enacted according to needs as the program developed, and additional STEAM tasks were introduced or amended. Table A1.1 provides a summary of participant numbers, PL aim and the number of sessions from Year 1 to Year 3.

Table A1.1 Case Study 1 – STEAM 1 PL summary

STEAM 1 Year 1	Number of sessions	Participants
Professional Learning	Six	School 1 executive and team teachers from various disciplines/faculties
Program Delivery to students	Six consecutive days	Year 7 – whole cohort immersion 120 students aged 12 – 13
Aim	To develop and deliver a quality STEAM program in order to up-skill teachers and provide opportunities for students to participate in connected learning	
Evaluation – post delivery	• Three sessions with STEAM team teachers • One session with school executive	
Sustainability	Re-delivery in following year	
STEAM 1 Year 2	Number of sessions	Participants
Professional Learning	Two	Original team teachers and new recruits from various disciplines/faculties.
Program Delivery to students	Eight consecutive days	Year 7 – whole cohort immersion 120 students aged 12 – 13
Aim	To further develop the quality STEAM program in order to up-skill teachers and provide opportunities for students to participate in connected learning.	
Evaluation – post delivery	One session with school 1 PBL coordinator	
Sustainability	Re-delivery in following year	
STEAM 1 Year 3	Number of sessions	Participants

Professional Learning	Three	Original team teachers and new recruits from various disciplines/faculties.
Program Delivery to students	Eight days scheduled over two weeks	Year 7 – whole cohort immersion 160 students aged 12 – 13
Aim	To further develop the quality STEAM program in order to up-skill teachers and provide opportunities for students to participate in connected learning.	
Evaluation – post delivery	ongoing	
Sustainability	Re-delivery in following year - ongoing	

2017 - February

Desire to *lead by example* was the major directive from the Principal at School 1. Collaborative features of the program were viewed as motivation for acceptance of transdisciplinary goals for teachers *and* students. Such strong intention was pitched to fellow executives, encouraging uptake of the STEAM strategy merging Design Thinking and PBL methodologies. 'This is Us' was confirmed as an appropriate title for the STEAM program. 'This is Us' aimed to broadcast how School 1 integrated play, curiosity, fearlessness, purpose and passion (Wagner, 2012) with STEM collaboration, critical and creative thinking, in order to establish School 1 in a strong competitive position within the local community. Ensuing discussion led the executive to collectively and categorically acknowledge that '*connectedness is integral to a positive human experience*'. Qualified intrinsically through the Principal's words: "*We do not want to be left behind*". Significantly, numerous additional unifying reasons for pursuing the STEAM PBL program at School 1 were articulated:

- *To provide students with an experience and understanding of ways we can engage with the local community and tell their stories via STEM learning and STEAM making.*
- *To encourage empathy as a way to solve problems.*
- *To discover how thinking, learning and communicating can emerge from experimenting, creating and making.*
- *To provide an adventurous, innovative and surprising ways of connecting and learning.*
- *To value the experience of patience and perseverance.*
- *To promote STEAM as a way of viewing the world as an interconnected entity.*

The task ahead was to engage and enthuse staff in order to commandeer a group of teachers to form a STEAM team responsible for learning the transdisciplinary capabilities required for successful STEAM PBL program delivery.

2017 – April, May, June

PBL programs typically include a ‘hook event’ as the initial learning experience, in the form of an excursion or visiting speakers, or both. School 1 personnel were reasonably well-versed in the PBL model, however, being new to integrated STEM/STEAM practice led to myriad options for the hook event, as well possible STEAM learning tasks for inclusion in the STEAM PBL immersion. Taken from the range of mooted projects, Table A1.2 indicates the *actual* projects chosen for inclusion. Components of each task have been aligned in relation to the corresponding STEAM projects outlined in chapter 4. Reasons for inclusion were largely due to the viability, skill, experience and enthusiasm of School 1 personnel, those who self-nominated in support of the STEAM PBL immersion.

Table A1.2: STEAM Learning tasks developed for inclusion in Case Study 1 – STEAM 1.

STEAM TASKS		CONCEPT	SUBJECT TEACHER INCLUSION	STEAM PROJECT ALIGNMENT
STEAM LEARNING ACTIVITIES DEVELOPED AND DELIVERED IN STEAM 1 CASE STUDY	1	'STEAM City' assembled from folded light structures incorporating mathematical patterns and geometric construction (including concepts of binary in pattern making).	Visual Arts (VA) Mathematics Science.	**1 – BINARY** **2 – LUMIFOLD**
	2	Community language and communication incorporating welcome words in diverse languages, interactive via Scratch coding and Makey Makey circuitry. Coding the soundscape for audience interactivity via programmed sensors.	Languages TAS/Engineering VA.	**6 – THIS IS US**
	3	Group and individual data mapping via digital geographic information system (GIS) tools describing individual student characteristics, using digital image manipulation and augmented reality (AR) technologies.	HSIE English VA TAS/Technology	**5 – THIS IS ME**
	4	Automated transport incorporating Lego Mindstorms™ robototics programming (to be used in the context of navigating through STEAM city structures).	TAS/Engineering Mathematics Science	**3 – FUTURE MOVERS**
	5	Visual autobiographies represented in digital imagery presented on geometric faces of a hexaflexagon. Digital video recording of the artefact representing collective stories for exhibition, presented in one single video loop (see Figure 4.21)	Mathematics English VA	**4 – FLEXTALES**

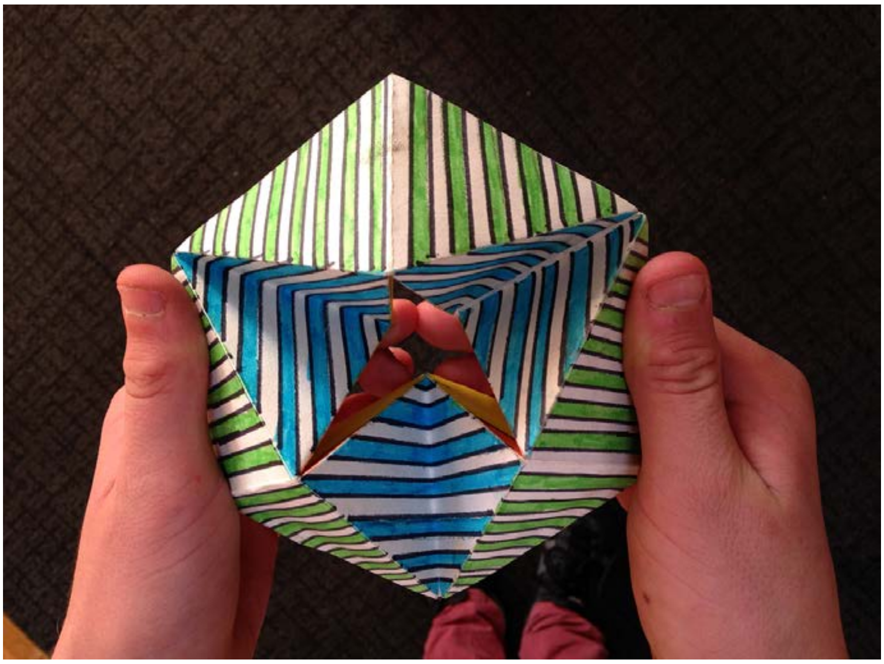


Figure 4.21: Hexaflexagons are four sided structures incorporating hidden geometries. That is, one face is always hidden while the other three faces are visible.

'This is Us', was introduced as the formal title to the Year 7 program aiming to explore STEAM concepts as a way of making connections between individual and collaborative experience and the wider world. Teachers self-nominating for inclusion in the STEAM PBL Immersion at School 1 represented a range of faculties; English, Science, Maths, HSIE, VA, Technology and PDHPE. In the first year of STEAM 1 case study, the team participated in three PL sessions related to the program. PL aimed to explore the wide-ranging rationale supporting a case for change in education. PL also introduced 'design thinking' strategies similar to the session undertaken with the School 1 executive in February. S1T1 provided further explanation of the School's PBL incentives and exposed the driving question for the STEAM PBL program: *How might we better connect with our community?* Discussion of PBL at this time included strategies to incorporate STEAM learning into the PBL model and indicators of how the A in STEAM might serve to illustrate connections between subject areas represented within the program. Six of the PL meetings are outlined in Table A1.3, including content coverage and skill building provided collectively or during one-on-one PL sessions between the researcher and individual teachers.

Table A1.3: Outline of PL session content over three days within STEAM Case Study 1.

PL SESSION	Professional Learning CONTENT	STEAM 1 Participants
Day 1 am	• Introduction to STEAM PBL and the case for change • Design Thinking explained and applied to aspects of the STEAM PBL program • Exploring the nuance of the guiding question • Brainstorming the activity content for each proposed STEAM project • School 1 BYOD policy and requirements • Familiarising teachers with DoE's "G Suite" resource • Setting up Google classroom for use within the program Experience sampling – gauge concerns and plan for future PL	9 teachers 1 researcher
Day 1 pm	• STEAM PBL program overview • Benefit of professional learning and planning: ○ Locating and using existing resources ○ Access to external providers ○ Commitment to extra curricular PL ○ Limitations: ▪ Time ▪ Skill ▪ Capabilities ▪ Appropriate training ▪ Confidence • Journey/empathy mapping to understand how the STEAM experience might be perceived from the students' perspective • Construction of Lego Mindstorms™ robotic vehicles for use in STEAM PBL. • Actions for next PL session*	9 teachers 1 researcher
*	Outcome and feedback from PL Session 1 was presented to the School 1 executive three weeks later. This was not considered Professional Learning.	MS PBL Principal S1

PL SESSION	Professional Learning CONTENT	STEAM 1 Participants
Day 2 am + pm	• Half day individual PL session for "Future Movers": ○ Robotics – Lego Mindstorms™ • Half day individual PL session for "This is Us": ○ Digital mapping using *Scribblemaps* ○ *Photoshop* instructions	Researcher Ms OL Ms AV
Day 2 evening	Three-hour evening PL session for "This is Us" via collaborative drive using Google docs: • Instructions for the use of 'Aurasma' Augmented Reality (currently renamed 'HP Reveal')	Researcher Ms EP

Table A1.3 cont.: Outline of PL session content over three days within STEAM Case Study 1.

PL SESSION	Professional Learning CONTENT	STEAM 1 Participants
Day 3 am	• Ms AV leads "This is Us" part 1 learning: ○ Scribble maps ○ Photoshop ○ File preparation and exporting • Ms EP leads "This is Us" part 2 learning: ○ Augmented Reality (AR) introduction ○ Applying AR technology to "This is Us" ○ Troubleshooting • Mathematical paper folding led by myself (the researcher) • Ms OL leads robotics programming: ○ Relevance ○ Lego Mindstorms™ interface ○ Planned student challenges for STEAM PBL ○ Needs and troubleshooting	3 lead teachers 6 team members 1 researcher
Day 3 pm	• Researcher leads Flextangle project learning ○ File management ○ Digital image manipulation ○ Output ○ Construction • Ms YG leads Scratch Coding learning ○ Creating narrative animations ○ Communication with Makey Makey™ circuitry ○ Needs – hardware and software ○ Troubleshooting • Ms PBL leads evaluation discussion ○ Student criteria for success • Teacher professional learning outcomes • Data collection	2 lead teachers 7 team members 1 researcher

2017 October

Success of the Year 7 STEAM PBL immersion and external exhibition resulted in ongoing delivery in subsequent years. All STEAM tasks culminated in some form of exhibitable component. The exhibition was visible representation of the range of STEAM learning at School 1, showcasing STEM+A efforts made by the school, its teachers, and Year 7 students. The objective was for as much audience response and interaction as possible. An exhibition 'team' of both students and teachers was nominated in each iteration of the STEAM program at School 1. The exhibition demonstrated amalgamated learning technologies in the form of:

- Robotics demonstration
- Mathematical light structures

- Collective stories accessible via digital video recording of hidden geometry narratives
- Augmented Reality access to autobiographical information embedded in data mapping and digital video
- Interactive soundscapes accessible to the audience via touch sensors and closed circuitry.

Strategic interactive audience experiences aimed to extend and promote greater understanding of the Arts approach to STEM concepts, and more specifically, to display the culture of the school and characteristics of its students. Therefore, at the retail centre, members of the general public were encouraged to touch, flex, feel, click, read and listen to the STEAM artefacts as well as question teachers and students about the learning embedded in the program (see Figure A1.2).

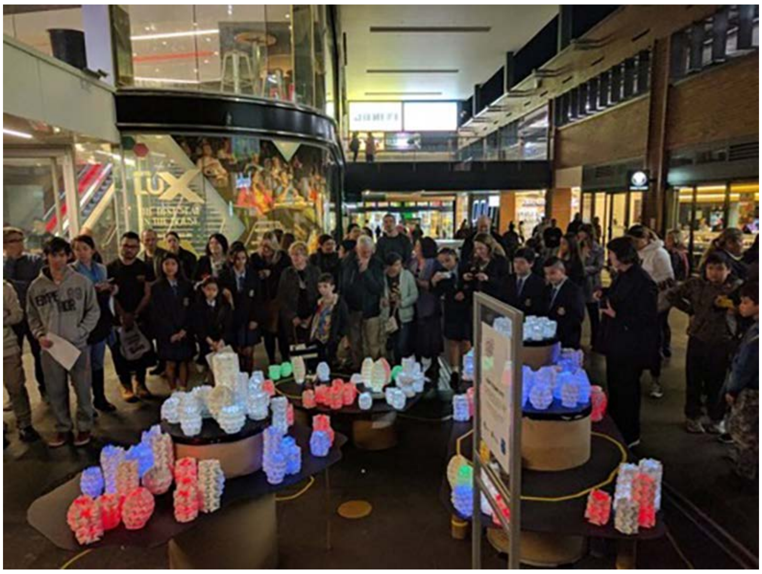


Figure A1.2: School 1 in STEAM 1, presents their exhibition at the local corporate retail centre.

2018 May

The second iteration of School 1's STEAM PBL program required similar PL, however, sessions were not as substantial as the previous year and required fewer whole days. Discussing my role of researcher with S1T1 *and* my responsibility of PL facilitator, it was decided to reduce PL provision in order to increase the sense of teacher *ownership* of the STEAM learning. Many of the original participating teachers returned to the program in Year 2 and continued to develop STEAM skills, providing peer-to-peer support for the new members of the team.

2018 June/July

In addition to the enhanced management produced by a more suitable physical location of each activity, instructional resources moved from physical to digital from Year 1 delivery to Year 2 delivery. File management in terms of achieving set benchmarks within each task was more effectively monitored. Submission of completed work was also more efficient. Improved efficiency was related to feedback and observation of both teacher and student achievement throughout Year 1 STEAM delivery, as well as updated software resources. Evaluation of the STEAM experience and artefact exhibition occurred concurrently, due to the restricted requirements of personnel necessary for the exhibition setup.

2018 October

Growing in strength and recognition, 'This is Us' at STEAM 1 was set for iteration for a third time. Observation of increased teacher skill and reduced trepidation related to learning and teaching unfamiliar topic areas was a prevailing feature as planning started for Year 3.

2019 March

Additional members were recruited into the STEAM team at School 1. Simultaneously, teachers were introduced to new STEAM concepts scheduled for inclusion in the third iteration of the program. Table A1.4 shows inclusion of increased coding and programming tasks in PL, as well as refresher PL outlining streamlined versions of original tasks related to 'This is Us' narratives.

Table A1.4: Outline of content for professional learning within Case Study 1 – STEAM 1.

2019 PL SESSION	Professional Learning CONTENT	STEAM 1 at SCHOOL 1 Participants
Day 1 pm	• Lumifold refresher PL for returning staff • Introduction to Lumifold for new STEAM team members • Introduction to mathematical theory related to Hyperbolic Parabolas – Hungry Birds project. • Introduction to Arduino programming in HB project • Hands-on learning related to 'Circuit Playground' multi sensor unit. • Sample programming using specific Circuit Playground online coding platform	10 teachers 1 researcher

Day 2 am + pm	• Introduction to maths theory related to Hyperbolic Parabolas – used in Hungry Birds (HB) project – NEW to the STEAM PBL • Introduction to Arduino programming used in HB project • Hands-on learning using 'Circuit Playground' multi sensor programmable unit • Sample programming using specific Circuit Playground online coding platform • STEAM PBL program overview • Journey/empathy mapping to understand how the STEAM experience might be perceived from the students' perspective • Construction of Lego Mindstorms™ robotic vehicles for use in STEAM PBL. • Actions for next PL session*	5 teachers 1 researcher
Day 3	• STEAM PBL program overview • Introduction to student booklet • Google classroom and Google drive setup • Digital navigation briefing and practice • Allocation of Year 9 student helpers • Familiarisation with software used in STEAM tasks	STEAM team Researcher

2019 April, June & July

Supplementary PL sessions were undertaken by new members to the STEAM team in preparation for delivery to an increased Year 7 cohort size. From Year 2 to Year 3, student intake to Year 7 at school 1 increased from 120 to 160. While the STEAM 1 case study undertaken at School 1 has been completed in terms of data collection for this research, the STEAM pedagogy developed for delivery at the school continues to flourish.

Case Study 2: STEAM 2

2016 November

With corresponding time frames, STEAM 2 emerged from a teacher PL event held at the end of 2016, before completion of the academic year in NSW, Australia. Ensuing informal discussion resulted School 2 invitation to participate, anticipating the development of STEAM learning with member of the Mathematics faculty.

2017 February

PL was conducted over three terms via two STEAM projects embedded into the routine Year 7 Numeracy program operating out of the Mathematics faculty. Maths head teacher and numeracy coordinator attended an initial planning meeting, joined by the Literacy Coordinator, one English teacher and school communications manager, and School 2 Principal.

Table A1.5: Case Study 2 – STEAM 2 PL summary

2019 PL SESSION	Professional Learning CONTENT	STEAM 2 at SCHOOL 2 Participants
Day 1 am	• Introduction to STEAM concepts • Planning for Numeracy deliverables • Hands-on skill development related to making Hyperbolic Parabolas • Confirmation of dates for the longitudinal STEAM program	4 teachers 1 Principal 1 researcher
Day 2	• Introduction to STEAM Binary Bugs project • Enacting the learning – probability & binary concepts • Constructing the bugs • Discussion of content in terms of curriculum links and development of related questions – worksheet creation	5 teachers 1 researcher
Day 3 pm Day 4 pm	• Introduction to Flextales • Software learning • Construction of Flextale physical unit • Discussion of content in terms of curriculum links and development of related questions – worksheet creation	1 head teacher Researcher

PL was scheduled as part of skill development for teachers delivering the STEAM program through regular Year 7 numeracy classes, incorporating one full day session related to the BB (see Table A1.5). Further PL was embedded informally into the STEAM program preceding the time of delivery to students. The artefacts produced from STEAM 2 were both physical and digital.

2017 March

STEAM begins with 'Year 7 Numeracy Day', an annual event aiming to link mathematical concepts with other key learning areas. Table A1.6 shows how HP making formed a gateway to literacy tasks and visual art / design challenges.

Table A1.6: Numeracy Day schedule for STEAM 2

SESSION 70 mins	CONTENT & ACTIVITIES	SCHOOL 2 TEACHING PERSONNEL
1	• Introduction to STEAM • Hyperbolic Paraboloid (HP) presentation • HP construction	Ms SV, Ms RC + 3 Mathematics faculty members staff members 2 x volunteers (ex-teachers)
2	• HP construction continued • Numeracy HP Worksheet • Experience sampling	

3	• Literacy activity related to STEAM and HP making experience	3 Maths staff members Ms ML 1 Technology teacher 1 Visual arts teacher Researcher (myself)
4	• Design Challenge – to design and make hats from the HP shapes – critieria for design must include mathematical references	

School 2 operates on a bi-weekly timetable. Two Year 7 groups were formed, requiring individual delivery to occur over two consecutive days per fortnight. Planning for this schedule included a PL session to learn specific content and construction techniques for application and creation of the first project, Binary Bugs (see Table A1.6). The PL session took place at the end of Term 1, before the full STEAM program commenced with the Year 7 cohort.

2017 April

STEAM 2 ran through 2.5 terms, beginning in Week 1 of Term 2 (see Figure 3.1) In addition to the program delivery, supplementary dates were added to accommodate digital video recording of project 2, with a view to presenting the video artefact in exhibition format late in Term 4. The projects delivered at School 2 were Binary Bugs and Flextales. PL sessions were primarily conducted to upskill the teachers in the BB project. The Year 7 cohort completed BB

yet did not create a final general exhibition as planned.

2017 August

PL related to Flextales occurred at a one-on-one session with S2T1, Maths Head Teacher at School 2. S2T1 sought additional technological support from an alternate staff member from the Technology faculty at School 2, before sharing the instructions with S2T2, Numeracy Coordinator. The Intention was to deliver the digital component of Flextales through Year 7 technology classes. However, the digital manipulation component of this project was ultimately delivered during Numeracy lessons with the assistance of maths teachers and the school's IT technician.

2017 October

The video artefact from Flextales was distributed privately amongst staff and was presented to students at the completion of the STEAM program (Figure A1.4).

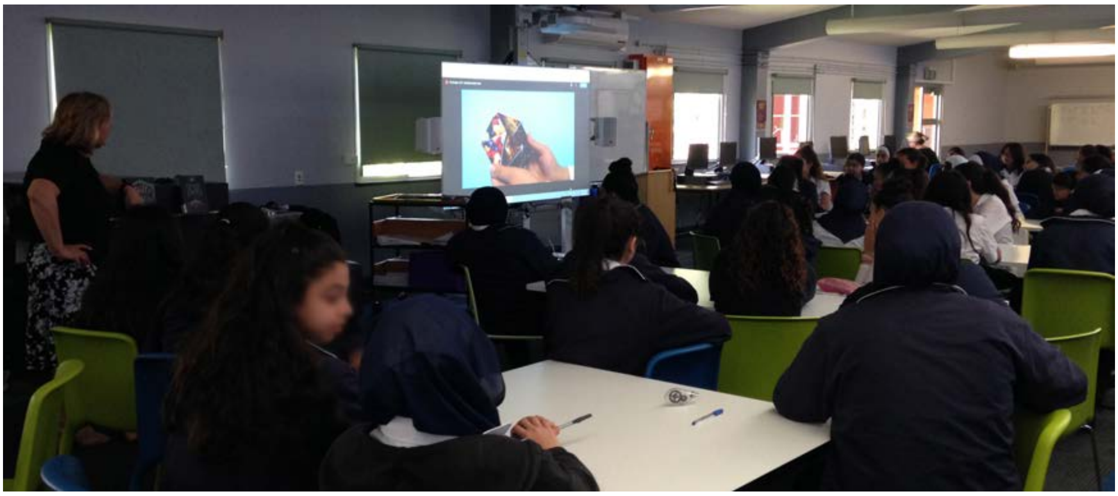


Figure A1.4: Flextale artefact – video artwork of combined Flextale creations in STEAM 2

Case Study 3: STEAM 3

2016 - November

STEAM 3 was situated in an inaugural STEAM Year 8 program at a high school for girls in metropolitan Sydney, instigated by the Mathematics and Science faculties in consultation with myself (the researcher) and Visual Arts teachers at School 3. The intention was to collaborate, and implement a program of integrated STEAM learning, concurrent to regular curriculum scheduled for delivery in the following year.

2017 - March

Idea generation from initial meetings with the STEM faculty at School 3 resulted in the development of the BB project. Teachers at the school requested the incorporation of increased mathematical content and a smaller making component. Integrating concepts of binary and probability within an aesthetic product-based project linked to biomimetic structures, offered many transdisciplinary possibilities.

Table A1.7: STEAM 3, School 3 PL and STEAM content summary.

STEAM 3	Number of sessions	Participants
Professional Learning	One	• Maths faculty HOD & classroom teachers • Science faculty HOD & classroom teachers
Program Delivery to students	One/two classes per week during a ten-week period within maths and science lessons, culminating in collaborative	Year 8 – whole cohort 170 students aged 13 – 14

	exhibition with Visual Arts.	
Aim	To develop one component of a larger STEAM program in order to support cross fertilisation of ideas between maths and science teachers while also providing opportunities for students to engage in STEM concepts via Arts methods.	
Evaluation – post delivery	Two interview sessions with pre-service and in-service teacher participants	
Sustainability	Re-delivery in following two years, and scheduled for ongoing iterated delivery	

Table A1.7 shows how teachers participating in the first iteration of STEAM 3, were required to attend one PL session to learn contextualise the BB concept and content.

2017 – May/June

BB was delivered to the Year 8 cohort (170 students) during Term Two, culminating in a large exhibition held at the school and attended by members of parent, teacher and local communities. A schedule of lessons was devised as planned alternatives from the regular maths, science and visual arts curriculum, designed to inspire, not to overwhelm.

2017 – September

School 3 teachers presented BB to peers in a regional mathematical association. Plans were established to re-deliver the BB component in the following year with significantly increased resources due to successful STEM grant funding.

2018 – May/June

The second iteration of BB was delivered to the Year 8 cohort (180 students) culminating in larger, more illuminated exhibition. Participating teachers did not require PL for BB. However, During November of the same year, a third iteration required PL engagement related to 'Lumifive', a version of Lumifold. Lumifive contains the same mathematical principles as BB. To date, the STEAM program is still in iterative delivery at School 3.

Case Study 4: STEAM 4

2016 November

STEAM 4 Case Study differs from STEAM 1, 2 and 3. STEAM 4 is a set of two PL sessions requested by members from a specific professional association. Liaison with members from the association led to confirmation of the sessions, held one week apart.

2017 May

Participants in STEAM PL included primary and secondary mathematics teachers. PL presented to the members was a range of STEM content with potential explorations from an Arts context. Focus on mathematics was emphasised and much of the content crossed ability levels, providing appropriate scalability to different stages of learning. Therefore, both primary and secondary trained teachers participated in a collective PL session in which BB was presented.

Table A1.8: STEAM 4, PL and STEAM content summary.

STEAM 4	Number of sessions	Participants
Professional Learning	Two	Primary and secondary mathematics teachers
Program Delivery	Three-hour workshop	27 teachers from 16 schools
Aim	To introduce ideas related to connected STEM and Arts projects and provide opportunities for teachers to explore connected concepts and experience maths-making for enhanced understanding.	
Evaluation – post delivery	Immediate feedback – no post evaluation	
Sustainability	Not known	

Table A1.8 indicates twenty-seven teachers participated in BB over two sessions. Similar to STEAM 3, the teachers undertook specific tasks related to binary and probability concepts to create patterns on pre-scored templates. (see Figure 4.6). Discussion of connected STEM + Arts concepts was followed by the physical activity of making the bug shapes, lighting the shapes with LEDs and evaluating the learning. Considerable questioning and note-taking occurred, with the expectation that individual project delivery across the wide range of schools represented at the PL would ensue. Feedback from STEAM 4 participants provides validation of the experience for the teachers.

Reference

Larmer, J., Mergendoller, J., & Boss, S. (2015). Gold Standard PBL: Essential Project Design Elements [Adapted from Setting the Standard for Project Based Learning: A Proven Approach to Rigorous Classroom Instruction].

Appendix E
Detailed STEAM Project Descriptions

Connections between the seven STEAM projects emerged through PL experiences. From this point on, each project is described in terms of process, in relation to *what* it was, *how* it developed and *who* was involved in PL. Subsequent to the description of the STEAM learning process, the chapter will go on to identify and explain *when* each project was enacted, denoting the STEAM learning product implementation over time.

Project 1: Lumifold

What is this STEAM project and how did it develop?

Initially developed outside of this study during my final years of high-school teaching, Lumifold (LF) is a mathematical paper folding activity using pre-scored paper templates to form three-dimensional shapes which are illuminated by the inclusion of light emitting diodes (LEDs). The foundation for LF derives from a collection of definitive guidelines curated by Paul Jackson, an origamist specialising in 'Sheet to Form' workshops for designers of all disciplines, as well as mathematicians, scientists, educators, and others (Jackson, 2011). In this study, I call the making experience 'flat to form'. The construction method is applied in both Lumifold and Binary Bug projects.

LF provided opportunities for the recognition and discussion of numerous mathematical and STEAM concepts while actively constructing auxetic arrangements. Auxetics is a representation of the so-called negative Poisson's ratio, wherein materials can be expanded in two directions at the same time. Poisson's ratio is used currently in bio-medical applications and sustainable fashion and textile design. During the making section of the project, paper templates of varying sizes are folded and manipulated into hills or valleys (up or down) according to origami *sekkei* rules and conventions. Origami sekkei is a Japanese phrase meaning 'computational' or 'mathematical' folding. There are two specific auxetic patterns inherent in LF folding outcome: a rigid cylindrical structure and a flexible spherical structure. Figure 4.4 (in thesis body) indicates samples of the final illuminated form constructed during STEAM PL related to the research.

During PL, teachers discover how "flat to form" concepts can be realised and connected to biological and non-human technological forms (see Figure 4.5). LF structures are lamps. Figure 4.6 illustrates the range of geometric shapes produced by folding the LF paper templates. The project focuses on learning ways of integrating art and design with STEM concepts in the classroom. Learning activities include exploring the foundation mathematics underpinning the lamp construction and the study of light and electricity.

Projects such as Lumifold involve specific development of trans-disciplinary and interdisciplinary practice. Learners gain an understanding of terminology used in paper engineering and in particular, the ‘glide reflection’ technique used in many applications in a range of industries. A glide reflection is a member of the seventeen wallpaper groups acknowledging mathematical rules that apply to tessellation of regular shapes. Analogous to BB, teachers discover how “flat to form” concepts can be realised and connected to biological and non-human technological forms.

LF provided opportunities for the recognition and discussion of numerous mathematical and STEAM concepts while actively constructing auxetic arrangements. Auxetics is a representation of the so-called negative Poisson’s ratio, wherein materials can be expanded in two directions at the same time. Poisson’s ratio is used currently in bio-medical applications and sustainable fashion and textile design. During the making section of the project, paper templates of varying sizes are folded and manipulated into hills or valleys (up or down) according to origami *sekkei* rules and conventions. Origami sekkei is a Japanese phrase meaning ‘computational’ or ‘mathematical’ folding. There are two specific auxetic patterns inherent in LF folding outcome: a rigid cylindrical structure and a flexible spherical structure. Figure A2.1 indicates samples of the final illuminated form constructed during STEAM PL related to the research.

Figure A2.1: Teacher PL Lumifold artefacts

Who participated in professional learning for Lumifold?

LF was enacted during STEAM 1 at School 1. Fourteen teachers participated in PL, with an additional 7 teachers recruited from feeder primary schools. Participant teachers represented a range of faculties, with one only, a mathematics expert. Two consecutive years of delivery resulted in 246 Year 7 students completing the construction of one or more Lumifold lamps to contribute to the 'STEAM City' exhibition combined with the study of robotics 17 Pre-service teachers volunteered to be part of the STEAM PBL projects at School 1.

Project 2: Binary Bugs

What is this STEAM project and how did it develop?

Binary Bugs (BB) developed as a method of exploring elementary symmetries in mathematics, combined with ideas related to probability, binary and biomimicry. Development of the visual design aspect of the project was based on understandings gleaned from a range of internet sources, such as PurpleMath.com (2017) . Other than exploring the base two numbering system and its relationship to the expression of binary numbers, the rest of the activity is unique to this study. That is, all designed elements such as patterning and construction of the 'bug' were created specifically for inclusion in STEAM 2 and 3. The BB project explores the complexity generated by interaction of two simple systems; a randomly created two-dimensional binary pattern and the structure of three-dimensional paper folding. The geometry of the 3D pattern embedded in the paper is enhanced by coin tossing to determine a 2D black and white (or colour/no colour) design. Hence the idea of binary merged with the mathematics of probability (see Figure 4.6 in thesis body).

The project aimed to apply those specific curricula aligned STEM concepts in a visual design environment. The sequence of images depicted in Figure 4.6 and Figure 4.7 show the application of a binary-related pattern onto the surface of a pre-scored paper template indicating the geometry related to folding a ‘glide reflection’ pattern. The binary sequence is determined by probability in a ‘heads or tails’ coin tossing activity, after which the patterned paper is folded into a biomimetic bug shape guided scored lines embedded into the paper. The lower middle displays a range of patterned shapes not yet fixed to the backing board or illuminated by LEDs. The board, or base, is designed to house a small LED (light) which remains accessible for switching on and off when the bug shape is attached. ‘Feelers’ are optional.

Symmetry and iteration are used within a ‘glide reflection’ pattern to determine both the surface design and the paper folding system. It is the glide reflection that produces the three-dimensional metaphoric form of the BB. Figure A2.2 illustrates a selection of differentiated binary patterns and the manifestation of each pattern from its flat state to the biomimetic “bug” 3D form.

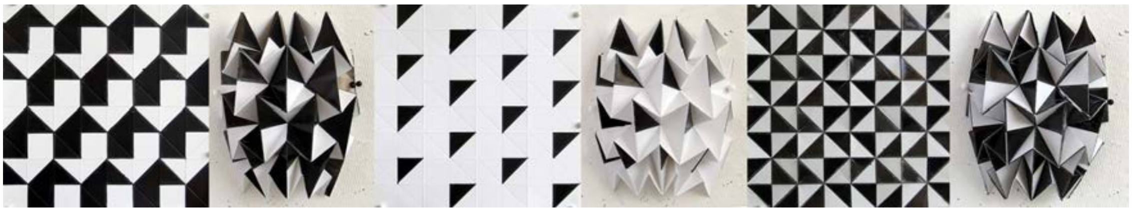


Figure A2.2: Sample binary pattern surface designs and folded Binary Bugs.

A range of bug sizes and shapes can be made using the templates, based on the choice of variables in grid numbers and the size of the initial single unit square (see Figure A2.3). Importantly, each shape explores how ‘flat to form’ concepts can be realised and connected to forms in nature. By flat to form, we mean transforming two dimensional shapes into three-dimensional forms. The bugs can also be illuminated using LEDs fixed into rigid card bases or lit by DIY paper circuitry (see Figure A2.3).

Figure A2.3: Differentiated bug shapes and a sample paper circuit created to light the BB form.

Who participated in professional learning for Binary Bugs?

The BB project was enacted through all four case studies settings included in the research (STEAM 2, 3 and 4 delivered the project in full form and STEAM 1 incorporated binary concepts into Lumifold (STEAM project 2). STEAM 2 delivered BB within the structure of their Year 7 Numeracy classes working with 84 students over two terms during one academic year. Simultaneously, BB was enacted at STEAM 3 during one term, delivered to 353 Year 8 students over two consecutive years. BB was the chosen STEAM learning activity for delivery of PL in STEAM 4. Participants in STEAM 4 included primary and secondary mathematics teachers from a regional mathematics teacher association. PL requested from the members was a range of maths focused STEM content with potential explorations connected to an Arts context. Throughout the research, at least 21 pre-service teachers also engaged in STEAM learning related to the Binary Bugs project.

Project 3: Future Movers – Robotics

Future Movers was enacted in STEAM 1 only. The project is a conventional learning model related to robotics technology using Lego Mindstorms EV3™ kits. In STEAM 1, all participant teachers contributed to the creation of the activity in which the robots were programmed using a sequence designed to navigate a path through a so-called 'city' made from LF artefacts (see Figure 4.8 in thesis body). We named this 'STEAM City' at the public exhibition of student work from School 1. The title "Future Movers" encouraged teachers to consider pedagogy related to speculative futures. Futures in which the development of autonomous vehicles poses questions related to how we might navigate local and regional areas in the anthropocentric environment. All teachers participating in STEAM 1 contributed to the construction of robotic vehicles during PL sessions in term 1, however the task of learning to program the robots was delegated to one teacher alone (see 4.9)

The title "Future Movers" encourages learning about speculative futures. Futures in which the development of autonomous vehicles poses questions related to how we might navigate local and regional areas in the anthropogenic environment. Figure 4.9 indicates the sequence of actions taken to program and test the devices, leading to scripting of code sequences instructing robotic units to *follow a line* around the LF structures at external STEAM PBL exhibitions.

Who participated in professional learning for Robotics?

All teachers participating in STEAM 1 contributed to the construction of robotic vehicles during PL sessions in term 1, however the task of learning to program the robots was delegated to one teacher alone. Thus, PL occurred through a single individual session with the participating teacher (ie. researcher and teacher). Year nine students, volunteering to assist in the STEAM PBL program were also included in the robotics PL session to assisting teachers in upskilling and troubleshooting potential issues related to the use of specific hardware and software. The participating teacher had no coding or programming experience. Likewise, the Year 9 student assistants were unfamiliar with this particular coding environment. Figure 4.10 displays the achievements of both, experienced by the end of the single day PL.

Project 4: Flextales

Flextales (FT) was a set of activities requiring the creation of a four-part visual narrative. Hence, the name of the project was 'Our Stories' in STEAM 1 and simply 'Flextales' in STEAM 2 (a flexible product that tells a story). The FT project comprised the manipulation of a sequential set of images applied to a four-sided geometric rotating shape, generally known as a hexaflexagon. The shape is manipulated, or 'flexed', to reveal a story while rotating from one hexagonal face to the next (see Figure 4.10 in thesis body).

The design of a hexaflexagon was not unique to this study, however its application as a sequential narrative that is primarily photographically based was new. Teachers in STEAM 1 in particular, contributed to FT iterations by way of investigating the mathematics inherent in the project. Much of the PL related to this project was related to the physical properties of units made with equilateral triangles compared with isosceles triangles. The characteristics of such hidden geometries was perplexing to both teachers and students. In addition to the mathematics, mapping digital images onto positional templates before printing and constructing was as challenging in teacher PL as in its delivery to students. Seven of twenty teachers participating in FT were mathematics specialists. However, the project melded rich literacy *and* numeracy components, providing opportunities for application over a wide range of subject areas.

Our Stories – what is this STEAM project and how did it develop?

Flextales (FT) is a set of activities requiring the creation of a four-part visual narrative. FT was enacted in STEAM 1 and 2. The FT project comprised the manipulation of a sequential set of images applied to a four-sided geometric rotating shape, generally known as a hexaflexagon. The shape is manipulated, or 'flexed', to reveal the story while rotating from one hexagonal face to the next (see Figure 4.11). The design of a hexaflexagon is not unique to this study, however its application as a sequential narrative that is primarily photographically based was new. Teachers in STEAM 1 in particular, contributed to FT iterations by way of investigating the mathematics inherent in the project. Much of the PL related to this project was comparing the physical properties of units made with equilateral triangles and isosceles triangles. The characteristics of such hidden geometries was perplexing to both teachers and students. In addition to the mathematics, mapping digital images onto positional templates before printing and constructing was as challenging in teacher PL as in delivery to students. Seven of twenty teachers participating in FT were mathematics specialists. However, the project melded rich literacy *and* numeracy components, providing opportunities for application over a wide range of subject areas.

The steps leading to the production of FTs begins with digital image manipulation to produce four individual images inside a hexagonal shape, mapped onto a single A3 page. The images demonstrate a story sequence. After printing, the hexagons are cut into triangles and arranged on a purpose-designed template so that when the Flextale is folded into its hexagonal shape, the images are positioned in appropriate alignment. This STEAM project is particularly useful for creative mathematical problem solving. Its nature is puzzling and steeped in rich mathematics and physics/engineering conundrums. STEAM 1 and 2 saw FTs producing dual aesthetic output: the artefact was both physical (the Flextale itself) and digital (the collective recording of the narratives). It melded rich literacy and numeracy components, with opportunities for application over a wide range of subject areas.

Who participated in professional learning for Flextales?

Twenty participating teachers from STEAM 1 and 2 represented various subject specific disciplines in PL during FT (see Figure 4.11 in thesis body). From this group, seven teachers were mathematics specialists. FT was delivered during STEAM 1 to 246 Year Seven students over two consecutive years, and delivered within STEAM 2 to 84 Year 7 students over one year. Seventeen pre-service teachers also volunteered for FT delivery, twelve of whom participating in STEAM training prior to delivery in STEAM 1 at School 1.

Project 5: This is Me

Digital image making & Augmented Reality – what is this STEAM project and how did it develop?

'This is Me' (TM) is a project co-created for inclusion in STEAM 1. Teachers learned digital mapping, image manipulation and augmented reality (AR) techniques to apply in the construction of a simple poster design. The designed outcome displayed information about its creators (a group of four), abstracted into geometric shapes and text (see Figure 4.12 in thesis body). TM was unique to the study, however the project made use of (then) existing digital platforms such as *Scribble Maps* (free online geo-location software), Adobe Photoshop, and online AR tools such as Layar, Aurasma, HP Reveal. Combining digital image manipulation with data visualisation, the project incorporated two methods of data representation and communication, requiring teachers to develop proficient digital skills, aesthetic sensibility and troubleshooting acumen, in order to facilitate efficient delivery to students. The mathematical content was related to area and perimeter calculations, coordinate plotting, and the creation of irregular polygons. The visual aspect required understanding of the elements and principles of design, with a view to producing an aesthetically pleasing 2D poster design. Figure 4.13 demonstrates how hidden information about the poster's creators was embedded into the 2D designs using AR, accessible via the appropriate app during the project exhibition.

The first digital technique entails collective data gathering from each student in groups of four, *Scribble Maps* (free online geo-location software) to locate each of their residences in relation to one another. The software also provides opportunities to explore metadata inherent in mapmaking. Mathematical theory is used to calculate perimeter and area measurement by plotting coordinates into a virtual map. The four-point shape created by the group presents as a polygon. The polygon represents a perimeter and using the tools specific to the software, the perimeter can be digitally translated into numeric data. Figure A2.4 tells the story of the sequential steps taken to produce the two-dimensional poster design based on geographical mapping described above. Mathematical terminology is reinforced by questions related not only to the input numbers but simultaneously encouraging connection and a sense of place in a physical environment or community. Data visualisation is created in groups using *Adobe Photoshop* software, resulting in a group poster design. The posters contain shared student data hidden in the polygon.

Figure A2.4: 'This is Me' STEAM project steps to perimeter mapping activity.

In TM, individual biographies are embedded into the paper prints using Augmented Reality technology (AR). Each group member records a short, scripted story, describing appropriate aspects of their life and contribution to their family, school and wider community. Each digital video 'vox-pop' was embedded into the digital poster design before printing. Individual stories are accessed through the printed poster using AR (see Appendix G for instructions). Figure 4.13 (in thesis body) shows how the students created and tested AR to reveal hidden content. Figure 4.13 also demonstrates the method of sharing individual videography with audience members during STEAM exhibitions in locations external to the school. Videos were accessed by smart device (phone or tablet) using the corresponding AR app.

The images in Figure 4.14 (in thesis body) represent two versions of the collective perimeter mapping of every student in the cohort collected over two consecutive years. When accessed through a specific AR app on a smart device, these images triggered an overview video document of the STEAM projects at the school, an alternative to the individual stories related to students accessed by their group data maps.

Who participated in professional learning for This is Me?

TM was developed for STEAM 1, therefore enactment of the project involved participation from fourteen teachers representing various disciplines/faculties. Over two years of the project's delivery, 246 Year 7 students contributed to the perimeter activity and data mapping exercise. Considerable PL was required for TM, as the project utilised basic digital manipulation skills and online navigation confidence requiring efficient and effective digital file management strategies.

Project 6: This is Us

Scratch coding and simple circuitry – what is this STEAM project and how did it develop?

'This is Us' (TU), was a follow-on project to 'This is Me'. Specific to STEAM 1, where the overall STEAM program was based on a PBL question of "How might we better connect with our community?", TU involved the creation of a scripted story, recorded and animated using coding technology. All teachers in the STEAM team were introduced to 'block coding', the model of learning devised for TM. However, the task of developing a detailed unit of work related to Scratch™ coding and Makey Makey™ was relegated to one teacher, expressing the intention of building coding technology into regular curriculum planning outside of the Year 7 STEAM PBL immersion. The collective PL was useful in devising strategies to scaffold and break down any coding issues into manageable parts, including how to organise and manage digital files logically, interpret numeric data and design and implement algorithms to solve problems. Teacher discussion during PL was associated mainly with transitioning themselves (and students) from a purported 'knowledge economy' to an 'automated economy'. Coding and interface images in Figure 4.15 (in thesis body), display TU as providing teachers with entry level block coding activities guided by Year 9 students during PL in STEAM 1. Such PL afforded teachers understanding of contexts in which 'This is Us' enabled students to personalise their programming skills.

TU was custom designed and delivered at School 1. The project exists within the context of STEAM 1 PBL, as a way of sharing the student experience with the wider community. TU entails the creation of a scripted story, recorded and animated using *Scratch* coding technology. Opportunities to enter a more advanced programming interface were also available through Scratch software. Interactivity was fashioned by linking Scratch coding with controllability via simple circuitry and sensor activation. Makey Makey™ devices were used to program spoken word into interactive functionality developed specifically for audience participation at the STEAM PBL exhibition (see final image in Figure 4.16). Makey Makey™ is an invention kit that uses a circuit board, alligator clips, and a USB cable to create close loop electrical signals through everyday objects, which in effect, replace keyboard or mouse click commands. While typically viewed as primary level STEM, Makey Makey™ provided immediate feedback loop experiences for the teachers using it for the first time. Given the cultural diversity of School 1, stories and song in diverse community languages was considered the best way to address the PBL guiding question of *how can we better connect with our community?*. Community language was integrated into the activity requiring students to code both sound and movement, and in the third iteration of STEAM at School 1, flashing lights were coded using Circuit Playground™ devices.

Who participated in professional learning for This is Us?

Many participating teachers in STEAM 1 had no coding experience, finding entry level block coding to be a first interaction with visual computational thinking. All teachers in the STEAM team were introduced to the model of learning devised for TM, however, similar to Project 3 – Robotics, the task of developing a detailed unit of work related to

Scratch Coding and Makey Makey was relegated to one teacher, expressing the intention of building coding technology into regular curriculum planning outside of the Year 7 STEAM PBL immersion. PL used strategies to scaffold and break down problems into parts, organise and manage digital files logically, interpret numeric data and design and implement algorithms to solve problems.

Project 7: Hyperbolic Paraboloids

What is this STEAM project and how did it develop?

Project 7 is a paper engineering experience in which the transformation of a flat piece of paper into a three-dimensional shape is extended to create a range of polyhedra. Teachers in School 2 participated in this PL, to co-create an activity for inclusion in the Year 7 'Numeracy Day', pre-empting the rest of the STEAM program. The HP project was not enacted in other case studies. The activity is included in the STEAM research range due to its combined numeracy and literacy inputs to the activity, and its effect on the participating teachers. Related to techniques used in Lumifold and Binary Bugs, the 'flat to form' experience transforms the paper material into a representation of the mathematical shape combining two conic sections: hyperbola and parabola. The shape is recognised as both hyperbolic paraboloid (HP) or parabolic hyperboloid. The HP shape represents an infinite surface in three dimensions. It has both hyperbolic and parabolic cross sections. It is a tactile way of introducing concepts related to abstract mathematical theory, as well as plotting, graphing and parametric variations in mathematics. Singular or united, the properties and characteristics of the HP shape provided scope for a variety of making applications that were both intrinsically mechanical and conceptually metaphorical. The activity offered rich STEM content with tangential STEAM possibilities (see Figures 4.16 and 4.17 in thesis body).

Who participated in professional learning for the Hyperbolic Paraboloid STEAM activity?

Teachers in STEAM 2 participating in PL for HP brought numeracy and literacy inputs to the activity. Briefed very early in the school year, introductory STEAM was proposed in the form of a whole day program in which 84 Year 7 students would engage with simple mathematics related to HPs, followed by a literacy task related to perseverance and fearlessness. Combined numeracy and literacy tasks resulted in a design challenge based on mathematical concepts, working towards the creation of a hat. PL teacher discussion led to the collaborative development of four STEAM activities, planned for inclusion in the Year 7 Numeracy Day at School 2 (see Figure 4.18). Six mathematics teachers would go on to operationalise the STEAM program during the following terms and attend PL sessions appropriate to those projects.

Appendix F
Sample of process for teachers – STEAM 1 'This is Me' AR project

STEAM 1, 2 and 3 involved much process driven guidance and instructional testing in order for teachers to grasp where the students might stumble over directions in the STEAM learning activities. The highlighted text is from the original notes.

This is Me

Technology: Photoshop, Scribble Maps and Augmented Reality (AR)
Students work in groups of 4

TRIGGER IMAGE
Students will create a group work based on where they live, their own portrait and some biographical information. The artwork will be printed colour A3 size at school. Group AR will be embedded into this artwork. Some examples of the A3 artworks will be exhibited in the final exhibition with students demonstrating the AR (probably using Aurasma for this).

COLLECTIVE PERIMETER MAPS
A larger work A1 (black and white) will be created using the images generated by the groups. This will be printed economically and exhibited at the Stockland exhibition. The AR embedded into the A1 images will use Layar so that the general public can access the content. The content will be video or images generated during the PBL week – uploaded ready for Thursday 22nd launch. Students will be required to guide users through the AR to access the content.

What students will use to complete This is Me

- A digital map of the local area (provided on worksheet)
- A digital photo of themselves (inside their PBL pack)
- Their biography between 50- 70 words (inside their PBL pack)
- One other image (inside their PBL pack) to use in the AR
- Optional recording of the biography – audio or video

Workshop leader responsibility

- Set up Aurasma classrooms
- Check that all groups have access to the photoshop template file (this already has the map image in it)
- Check all students have text, photos (inside their PBL pack)

Process
Students will be provided with a simple worksheet to record calculations and information about this project and an A4 map of the local area that includes a distance scale.
Photoshop TRIGGER IMAGE

- A map of the local area will form the basis of the work. This map will include a scale indicating distance within the area. (Layer 1)
- Students will plot where they live by placing their portrait image on the location of their house. (Layer 2)
- Students will then link each image by drawing a line that follows the route from their location to the next location. Each student will take a turn at plotting the path. (Layer 3)
- Students then use the scale on the map layer to **estimate the length of the perimeter** of the area they plotted between their houses.

- Students record the perimeter length on their worksheets. E.g. 1.8 kilometres or 780 metres.
- Students then use Google Maps to calculate the perimeter accurately.
- The two measurements will be compared to see how close the student estimates are to the actual distances.

THIS MIGHT BE REDUNDANT NOW IF WE USE "SCRIBBLE MAPS"

SCRIBBLE MAPS – CREATING THE PERIMITER MAPS

- Students look at the map of the local area on their worksheet to plot the address of the location of where each of them lives.
- Starting from one location, Students use the scale on the map to estimate the cumulative distance between their houses. This is the perimeter.
- Students record the perimeter estimate on their worksheets.
- Students then open Scribble Maps distance calculator in their browsers: https://www.scribblemaps.com/tools/distance-calculator
- In Scribble Maps, make sure that the map is in TERRAIN view.
- Use Scribble Maps to enter the same locations and work out the accurate perimeter using the tools to draw a path showing the route that you would take to get to each house.
    - Map 1 uses Driving tool to create a map of the roads taken from one location to the next and then back to the start.
    - Map 2 uses Rumbh line tool to create a simple polygon (distance by air)
        - Students will need to enter the first location again to complete circuit from the first house to the last.
- Record the actual perimeter (by road) on the student worksheets.
- Record the perimeter (by air) on the student worksheets
- Comment on the differences… (metres, kilometres, feet, yards, nautical miles etc)
- **Students take a screen capture of the Scribble Map 2 image.**

PHOTOSHOP – CREATING THE TRIGGER IMAGE

- Open the Scribble Map screen capture in Photoshop
- Open the "This is Me" template PSD.
- Copy the Scribble Map image into the "This is Me" template.
- Choose "Save as" and name the file using YOUR GROUP INITIALS + Perimeter number in metres (no decimal places). For example **MAAE1280**
- Transform the map image to fit the size of the template (does not have to be perfect fit). This will be Layer 1
- Students now open their individual portrait images by navigating to their PBL pack.
- Each student will copy their own portrait image and paste it into "This is Me" template – this should automatically create a different layer for each student portrait.You should now have 5 layers???
- Resize the portrait images and place them at the location of where they live on the map. (This should be at one of the corners of the polygon created in Scribble Maps)
- Optional – students might play with filters to create different visual effects for their portrait? **NO OPTIONS**
- Remember to save the PSD with layers then choose THE FOLLOWING

"Save for Web" to create a jpeg file to use with Augmented Reality Where?), then choose

- "Save as" to create a PDF of this file to upload for printing (Where?)
- Go back to Scribble Maps and click on the "area calculator".
- Students use the area calculator to create a polygonal shape that indicates the shape of the area that contains the location of their houses. DO WE NEED TO DO THIS? NO

Measurement 1	Measurement 2	Measurement 3
Estimated perimeter	Actual perimeter (by road)	Actual perimeter (by air)

PHOTOSHOP – CREATING THE COLLECTIVE PERIMETER MAP

- Redraw the polygonal shape in a new layer
- Fill this shape with black
- Open the "Year 7 Perimeter Maps" photoshop document
- Copy the polygon from "This is Me" to the "Year 7 Perimeter Maps"
- Save with your group name
- Upload to the appropriate folder in google classroom

CREATING THE AUGMENTED REALITY OVERLAY CONTENT

Aurasma

Students will embed the map image with information about themselves using an augmented reality program. The information has been pre-created using one of the methods below. They might like to more than one image if there is time. Works will be printed out and titled with the mathematical information they obtain by making their A3 group image maps. The content hidden inside the colour A3 "This is Me" images will tell the individual story of each student in the group in a video selfie clip.

OPTION 2 is the best option and most achievable.

OPTION 1: STATIC IMAGE (created in Photoshop) I think it is too difficult to give any choice at all

- Students create an A4 size poster that includes image(s) and text about themselves. Limit the images to maximum of three.

OPTION 2: VIDEO (created using any video editing software) iPads?

- Students record their short biographies and make a small montage using the images saved in their PBL packs.
  OR
- Students record each other on the day in a more "selfie " style using info from their biographies but NOT ALL OF IT
- **Length MAXIMUM 45 seconds**
  - **Video must be downloaded to PC**
  - **Video must be converted to smaller file format – H264 (Mpeg)**
  - **Students will convert videos and save them before uploading**

OPTION 3: Audio (created using any audio recording software – saved as MP3)

- Students record their biographies as a sound file only
- **Length MAXIMUM 20 seconds not supported by Aurasma**

OPTION 4: STATIC IMAGE VIDEO with audio (created in Photoshop and any video edtiting software)

- Students record their biographies as a voiceover to the static photoshop image.

The options in yellow are the least desirable, students will most likely choose option one or two so do we need these at all?

VERY IMPORTANT

Students must save their overlays ??? what is an overlay?? with their name and overlay in the filename. For example: "FirstName/LastName overlay"

Appendix G

Sample instructions – STEAM 1 'This is Me' AR project

The instructional resources produced for the research were tested in collaboration with the participating teachers. Testing proved an invaluable experience for improving the way tasks were delivered from one STEAM program to the next. Constant iteration provided much evidence of projected teacher ownership of individual projects within the greater STEAM programs. The sample set of instructions presented here is the result of teacher and researcher testing. In nearly all instances within the research, these step-by-step directions indicate the resource co-created for student instruction within STEAM 1 and STEAM 2. Please note that the samples have de-identified any specific nomenclature that may expose the name of the participating school, teachers or students.

STEAM

STEAM PBL Project "THIS IS ME" HANDOUT 5

Instructions for creating the trigger images and overlays for "THIS IS ME" STEAM PBL Project – AURASMA (Augmented Reality)

BEFORE WE START IT IS VERY IMPORTANT TO UNDERSTAND THE AURASMA TERMINOLOGY:

Aura, Trigger and Overlay

The ***aura*** is what Aurasma calls the process of creating augmented reality content inside an image.

The ***trigger*** is the static images that people focus on using the camera function on their device and the Aurasma App.

The ***overlay*** is the content that is embedded inside the trigger image. It is what is seen when people hover over the trigger with their device.

You must upload your video to the Year 7 collaborative drive before starting this activity. See your TSO.

STEAM

STEAM PBL Project “THIS IS ME” HANDOUT 5

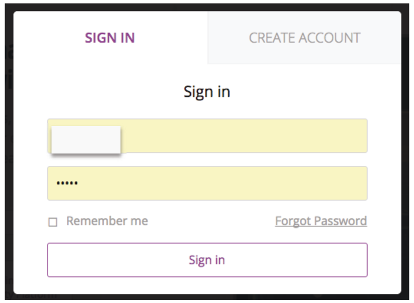
STEP 1

1. Launch your web browser. **USE GOOGLE CHROME**

2. Search for Aurasma Studio or click on this link to go to Aurasma Studio: https://studio.aurasma.com/landing

STEP 2

3. Click on the login button and login to your STEAM PBL Aurasma account using these details:
username: XXXXXXXX password: XXXXX



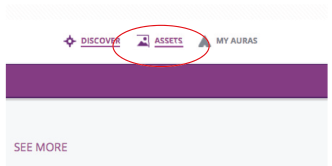
There can be many users on one account. We will be able access all trigger images, overlays and auras created collectively. The group leader can manage this.

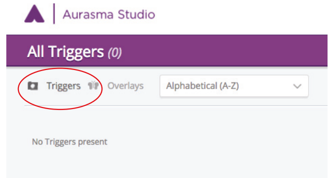
STEAM

STEAM PBL Project “THIS IS ME” HANDOUT 5

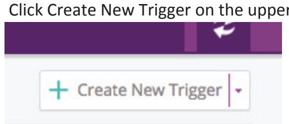
STEP 3

4. Click on the “Assets” tab at the top of the screen to start uploading your files for the project. Choose the “Triggers” menu first.



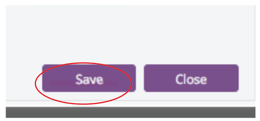


5. Click Create New Trigger on the upper right side of the screen.



6. Name the image with your Group Initials plus the word “trigger”. For example **MAAE Trigger**.

7. Upload the jpeg of your “this is me” poster image that you have already created and saved. Click on the browse tab to find your image. You can write a description if you want. Click “Save”



Aurasma will then process the trigger image jpeg file. You will now see your trigger image in the Trigger menu. When you refresh the browser, you will be able to see all the triggers created for this project.

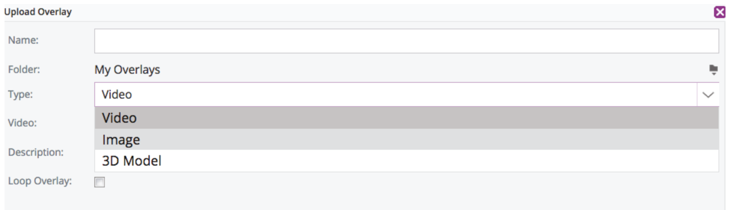
STEP 4

The overlay is where you will put the content inside the trigger image. The overlay can be video, audio or static images.

8. Click on Overlay icon to access the Overlay menu.
   This is next to the Trigger tab at the top left side of the screen.

9. Click the “create new overlay” button at the top right side of the screen.

10. Choose Video in the drop down menu.



11. Name the overlay with your group initials plus the word “overlay. Upload this file in the same way as you uploaded the trigger image. For example: **ATLH Overlay**

If we are using Video for the overlay, it must be converted to Mpeg with H264 codec first. Large files may be problematic to play. Reduce the file size of the video when you export it from whatever movie making app you are using.

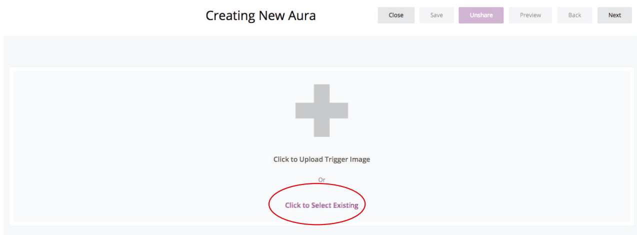
*Video files will take longer to upload.

You will now see all the overlays in the account, ready for use in an “AURA”. The Aura is where you put triggers and overlays together. There might be images and video. We are not working with 3D models for this project.

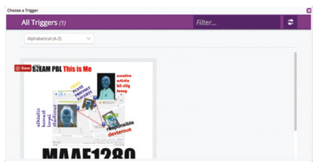
STEP 5

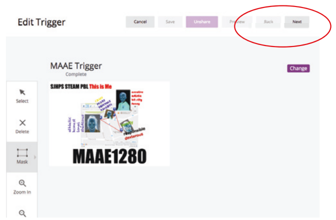
12. Click on “My Auras” at the top of the screen and click on “create new aura”.

13. Choose “select existing” to access the files you saved into the Assets folder.



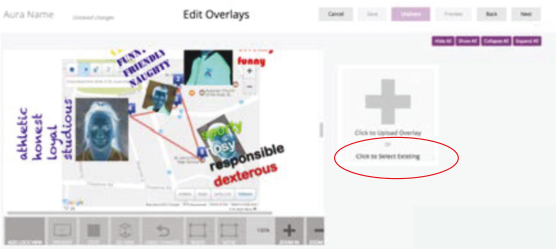
14. Choose your trigger from the list of files. When you choose your trigger, you will automatically be taken to the edit field. When you can see your trigger image, click “next”.

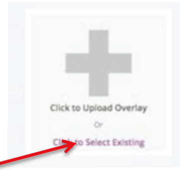




STEP 6

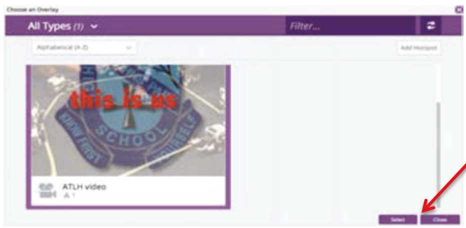
Now you will upload your “overlay” to the trigger image. This is the content that will be seen when people use the Aurasma Augmented Reality app to hover over your “This is Me” poster.





15. Click on “select existing” to access the overlay image.

16. Choose the overlay that you want to use by clicking on the image and then press “select”.

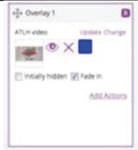
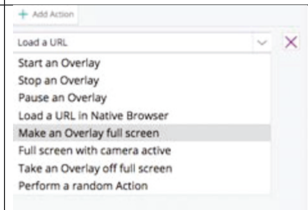
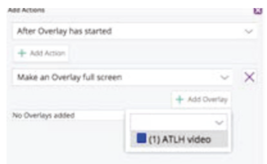


17. Use the zoom tool to see where you want the overlay to sit on the trigger image. Resize the overlay image to the desired position.

STEP 7

18. **Now you must add actions to your overlay.**

This is how you control what happens when people view your trigger image using the Aurasma app. For this project, follow these recommendations:

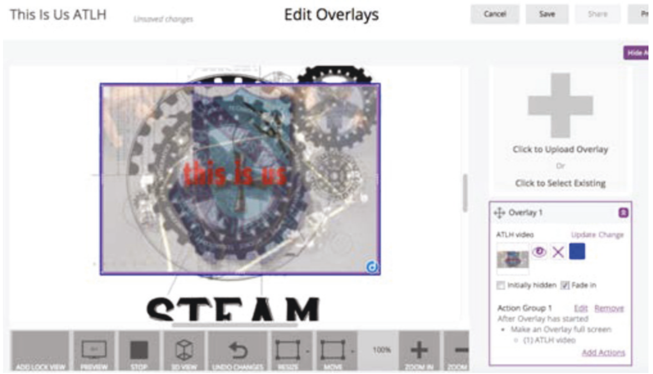
Choose if you want the overlay to fade in or not.	 **Do not press the X or your overlay will disappear!**
Choose “after overlay has started” from the drop down menu, then click “add action”.	
Choose “make overlay full screen”, then click “add overlay”.	
Choose the overlay that you want the action applied to – it should be the one you created and uploaded already.	
Click “done” and then “save” at the bottom of the screen.	

STEAM

STEAM PBL Project “THIS IS ME” HANDOUT 5

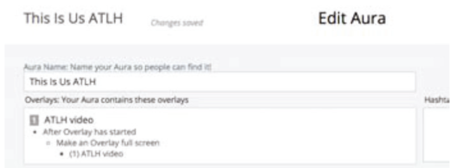
STEP 8

You should now see the list of actions attached to your overlay displayed in the edit screen of your aura.

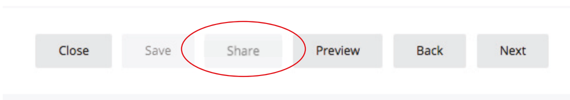


19. Click “save” at the top of the screen. Click Share, **Then click Next.**

20. Name the Aura with your Group Initials. For example: **“This is Us ATLH”**



21. **Click Share.**



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