What teachers learn from science and arts integration in a design-based learning framework: An Australian study

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Secondary teachers face a plethora of advice on why and how to integrate science with the arts for mutual benefit. Diverse rationales for this integration are matched by wide variation in recommended programs. However, there is limited research on what exactly teachers learn, or need to learn, over time beyond the life of any particular approach or topic, to succeed. In this paper we contribute insights into this issue by analysing, in the light of relevant literature, participant teachers' learning after four years experience of a standalone, two-day annual program that aimed to integrate science and the arts in a whole-school approach. Our case study entailed interviews with the principal and key participant teachers, observational notes on program enactment, and participation in teacher planning and review meetings. We found that: (a) participant teachers perceived multiple benefits from this curricular innovation; (b) the integration was enabled by a design-based learning framework, and (c) diverse conditions were needed for this innovation to be sustained, with implications for other forms of program integration.

Changing the curriculum

> I don't think you can lose by becoming involved with other subjects. If you cloister your understanding of the world in one specific area you are missing out on a lot. (Teacher 1)

> When we planned together in our team and cross-curricular, it made us big picture thinkers and we have to have that sort of thinking to be able to move forward. (Teacher 2)

Two arts teachers made these reflections after experiencing four years of an annual Arts/Science Festival in an Australian regional secondary school (2015-18). Their comments indicate their sense of perceived benefits and conditions for success. There is a long history of calls for teachers to integrate these two learning areas (Henriksen, 2014; Root-Bernstein, 1996), or to acknowledge aesthetic dimensions to science learning (Anderhag, Hamza & Wickman, 2015; Hadzigeorgiou, 2016). While advocates claim diverse reasons to justify this integration, programs that specify how it could or should happen vary markedly. This diversity reflects the reality that this integration is not yet a universal mainstream secondary school curricular practice. Despite suitable content for integration being articulated, advice on how to achieve integration is missing from national policy documents (Katz-Buonincontro, 2018).

There is also limited research on what exactly teachers learn, or need to learn, over time beyond any particular approach or topic, to succeed. In this paper, as part of an Australian

Research Council project on improving regional, low-SES students' learning and wellbeing (2017-2019), we aimed to contribute to this research by identifying what teachers in one regional Australian secondary school learnt from their experience after four years of implementing a short, whole-school program that combined arts and science subjects. Of the subjects that make up the arts in the curriculum, because of the design focus of the Festival, media arts, visual arts and visual communication design contributed directly to this program.

We report on participant teachers' learning at this stage in their program's evolution and, on the basis of this learning, offer suggestions about the conditions needed to extend this integration further into the curriculum. To contextualise this study, we first review relevant literature on the rationale for integrating the arts and science, and proposed approaches.

Why link science and the arts in school?

Economic, epistemic and pedagogical rationales are proposed for why science and arts should be integrated. The economic case is that arts creativity is needed in science-based innovation and in a future designer economy (Graham, 2020; Kalin, 2019), and that students therefore need to develop creative, science-based problem-solving capabilities in school (Taylor, 2016). The epistemic case is based on recognised complementary synergies between the two areas, evident in the growing practice of artists working alongside scientists in scientific research programs and dissemination (Arts at CERN, 2021; Eldred, 2016). Artists bring fresh perspectives, new conceptualising processes and creative flexibility to scientific agendas. They not only enhance scientific communication, but also function as designers, catalysers, and experimenters, contributing to what and how new scientific knowledge is generated and shared (Eldred, 2016). Conversely, access to scientific agendas and resources prompts new agendas, processes and outputs for artists (Arts at CERN, 2021). The pedagogical case is that an arts infusion into the science curriculum potentially enhances the appeal and meaningfulness of both subjects. For Graham (2020, p. 6), the arts infusion can encourage "reconstruction" and "critical self-awareness" in the curriculum. Researchers also claim that enacted integrations have improved learning outcomes in literacy for disadvantaged student cohorts (Stoelinga, Silk, Reddy & Rahman, (2015), and in science content (Hardiman & JohnBull, 2019; Taylor, 2016).

How to link science and the arts in schools

Researchers broadly suggest (a) diversifying the goals, methods, learning experiences and outcomes in each discipline, and (b) promoting an applied learning focus to science content (Henriksen, 2014; Root-Bernstein & Root-Bernstein, 2004; Taylor, 2016). Some researchers have attempted to incorporate more imaginative approaches into science learning, including student creative visualisation in representations (Ainsworth, Prain & Tytler, 2011; Tytler, Prain, Hubber & Waldrip, 2013) with promising results. Turkka, Haatainen and Aksela (2017), from their survey of 66 Finnish secondary school teachers, suggested that the most productive form of integration is based on a core of integrated content developed by arts and science teachers working together, combined with an experiential activities-based approach.

More specific prescriptions for integration tend to propose using inquiry projects and design-based learning (DBL). These processes are couched in varied frameworks, different time-spans and contrasting foci. Frameworks can include linking both subjects through a one-off science topic (Chu, Martin & Park, 2019; Tytler, Prain & Hannigan, 2020), multi-disciplinary STEM (science, technology, engineering and mathematics) or STEAM (science, technology, engineering, arts and mathematics) curricula (Hunter-Doniger & Syndow, 2016; Hardiman & JohnBull., 2019; Herro & Quigley, 2017; Holbrook, Rannikmäe & Soobard, 2020; MacDonald, Hunter, Wise & Fraser, 2019; Taylor, 2016), out-of-class programs (Baran, Canbazo□lu Bilici, Mesutoglu & Ocak, 2019), and one-off festivals and fairs (Keçeci, 2017). As noted by Turrka et al. (2017), in their review of enactments, inquiries variously focus on one overarching theme, a culminating artefact production, exploring a common idea, such as studying the properties of light, or a mix of these foci. Integrations are also broadly categorised as "transdisciplinary" (Holbrook et al., 2020), "multidisciplinary" and "interdisciplinary" (Turrka et al., 2017), but without definitional clarity or specificity in these features or in what new interdisciplinary insights and learning result from the integration.

Design-based learning (DBL) approaches usually entail a cyclical, reiterative set of stages. Students are guided to explore a specific real-world problem or issue while considering the audience or client needs, brainstorming possible solutions, and developing prototypes which they then test, review and refine into a product or solution. (Kim, Suh & Song, 2015; Intuyu Consulting, 2017; Taylor, 2016; Turkka et al.,2017). In this process, they are expected to learn about and/or draw on relevant curricular and cross-curricular knowledge and material resources, work with others to solve a problem, and to present their findings to peers and/or relevant audiences and clients. Using DBL to integrate science and the arts is claimed to be warranted because of synergies in inquiry processes in each subject (Turkka et al., 2017). However, the integration process needs to be negotiated by teachers in their particular school context.

Teacher learning

Research on what secondary teachers have learnt, or need to learn, from these varied enactments tends to be under-theorised, generic rather than specific, and sometimes overtly optimistic in the context of siloed prescriptive curricula (Moss, Godinho & Chao, 2019). Not surprisingly, researchers have found that teachers need to develop skills in "negotiation" (Turrka, et al., 2017, p.13) and "collaboration" (Herro & Quigley, 2017, p. 416; Graham, 2020, p. 6; Macdonald et al., 2019; p. 83; Tytler, Prain & Hobbs, 2019, p. 61). For Harris and deBruin (2018), "creative relationships between teachers and learners are dependent on the nurturing and promotive aspects of interactions and activities that can potentially fracture the siloed nature of subjects and predominant teaching practices" (p. 175). While these broad conclusions on teacher learning are reasonable, they tend to be "non-specific" (Robutti, Cusi, Clark□Wilson, Jaworski et al., 2016, p. 678), and do not offer a deeper theoretical perspective on what is at stake in this teacher change.

There is also an extensive literature on reasons why teachers embrace or resist curricular change, with researchers noting the importance of school leadership, teacher recognition of the need for change, and structural enablers and barriers (Clarke & Hollingsworth, 2002; Opfer & Pedder, 2011; Prain, Cox, Deed, Edwards et al., 2014). Cross-curricular teacher collaboration entails particular re-orientations in how teachers understand their own discipline-based professional expertise and its relationship to colleague expertise. Teachers need to share a broader than discipline-specific view of the goals and means of contemporary curricula. They need to learn exactly how to team-teach to enact this more open-ended curriculum (Prain, Blake, Deed, Edwards et al., 2018; Prain, Emery, Thomas, Lovejoy et al., 2021), and to recognise signs of success in their own practices and for student learners. We consider that teacher teamwork in general, where cross-curricular teaching of science and arts is just one example, remains under-theorised in terms of why and how it should happen, and what should count as local or general success indicators (Prain et al., 2021).

Theoretical framework

In theorising this teamwork, we turn to Anne Edwards' (2007. p. 1) cultural materialist perspective on "relational agency". In seeking to analyse core conditions for effective systemic renewal in learning sites, and drawing on Engestrom's (2005) sociocultural perspective, Edwards (2014) sought to "understand the interactional changes that produce systemic change" (p. 205). For Edwards (2015) relational agency entails participants interacting to create a network of combined expertise to enact shared goals. For Edwards, this agency pinpoints what teachers need to do, and learn from, to meet a broader view of the roles of different subjects in a new set of goals for schooling. We find Edwards' theory illuminating because it focuses on both the rationale for teacher teamwork and the indicators of effective, sustainable cooperative practices in action. According to Edwards (2007), bringing to bear different subjectivities and different sets of conceptual tools on any problem not only expands interpretation of the problem but also enriches the subjectivities of participants through awareness of others' expertise and interpretations. For Edwards (2007, p. 6), such a network foregrounds "responsibility to and for others", where a shift to the relational is "an important move in the development of meshes of mutual responsibility".

At the same time, teacher relational agency operates within a "nested agency" (Prain, Cox, Deed, Dorman et al., 2013), as teachers and students are constrained by structural, cultural and pedagogical assumptions, regulations, and practices, and actual and potential roles and responsibilities.

Conditions for effective relational agency include teachers and students being clear about how and why decisions are made on learning foci and complementary subject inputs, and building common knowledge about the means and ends of new collective goals. Teachers need to know why and how effective collaborative material and symbolic tools can be developed and knowledge shared. Material tools can include planning meetings, organisation of student groups, and artefact production, whereas symbolic tools include all documentation, including rubrics and prompts for student and teacher reflection on practices. Socially constructed boundaries need continuous review to ensure that shared long-term goals are served (Edwards, 2007). Teacher agency entails both responsibility and self-evaluation, where teachers consider the extent to which their work serves a "wider good" of student and staff wellbeing and learning (Edwards, 2015, p. 780). A meaningful curriculum is built when teachers and students "work alongside each other on culturally relevant problems which require the student to engage with public meaning" and discourses relevant to their own lives. The teacher's role is to "help the student continuously expand their interpretations of the problem" through developing appropriate concepts and skills (Edwards, 2014, p. 208). We consider that design-based learning is a practical way of achieving Edwards' view of a meaningful curriculum.

We apply Edwards' (2007) account of relational agency to analyse our case study that began as a modest curricular innovation at "Melaleuca" Secondary College to integrate science and arts in 2015. The program was modified over subsequent years, and continues to evolve as teachers perceive the curricular benefits for themselves and their students of working together.

Context of study

Melaleuca College is the pseudonym for a Year 7-10 state secondary college in a large regional city in Australia. The students at this school range in age from 11 to 16 years. The school is in an area of socio-economic disadvantage. With a current school population of 591 (295 boys and 296 girls) the school has 49 teaching and 25 non-teaching staff. In 2011, the school was rebuilt. Traditional classroom spaces were replaced by four large learning communities with vertical grouping of students from Years 7-10. Learning areas in each community varied from large open plan spaces catering for up to 100 students to small purpose-built learning areas for individual classes. This physical setting prompted teachers to be more open to cross-curricular collaboration (Prain, et al., 2013). Staffing was relatively stable, enabling teachers to build trust and familiarity with one another's practices and to recognise different strengths in individual teachers. Because of the distinctive features of this context, we provide a detailed account of the nature of the program and its evolution.

Program evolution

Since 2015, all teachers have collaborated on an annual two-day program which has evolved from an Arts-Science Festival with a science-based theme and a creative maker focus into a program more closely based on curriculum with a design-based process. Throughout the program's development the principal has been deeply involved and highly supportive, setting aside the regular timetable to devote two days to the Festival, allocating planning and review time, taking a leading role in the family celebration evening, and encouraging the program's leaders to look ahead with a view to extending cross curricular programs and team teaching.

2015-2016

The program genesis was two curriculum leaders (Teacher 1 and Teacher 3) discussing how the narrow partitioning of arts and science limited their students' observations and representations in both subjects. Their perceptions of potential subject synergies provided the impetus for the program. They proposed a whole-school two-day science/arts Festival where students undertake electives in which they applied and shared scientific understandings through arts-based creative design processes. The principal was strongly supportive of this initiative and encouraged its advocacy to all staff. Teachers teamed to offer practical workshops, in which students demonstrated their scientific understandings through a creative design process. These workshops entailed students using a broad range of resources, techniques and materials incorporating aesthetic considerations to create working models, demonstrations, performances, and solutions to problems.

2017
In 2017, to provide an additional rationale for the program, topics were linked more closely to the curriculum. Science teachers prepared students for the Festival in science classes leading up to the Festival which was held on 30 and 31 May, 2017. During the Festival, students made zoetropes, experimented with taking and developing photographs on pinhole cameras, constructed laser maze games and created digital images of pixel monsters. In these workshops, the scientific knowledge that underpinned the creative process was clarified by the teachers, incidentally in response to student questions as students worked on their projects. Still not satisfied with the rigour of the science content, the teachers considered further modifications that would link the program more closely to curriculum imperatives.

2018
In 2018, two factors led to further Festival changes. First, the state government had new priorities around cross-curricular studies and developing students' capabilities for this century (critical and creative thinking, ethical, intercultural and personal and social). The Festival was deemed ideal to develop students' critical and creative thinking abilities. Second, the school was to partner with a new technical college aimed at promoting links between industry and schools, with a curriculum organised around DBL (Intuyu Consulting, 2017). Through a consultative process, teachers negotiated the component disciplinary roles. The arts component entailed initial imaginative engagement with the problem and design possibilities, the use of a range of resources to create, test and refine a prototype for the project, and the creative communication of the project's intention to an audience. Science, technology and mathematics components were to be incorporated in a timely manner to investigate the robustness, practicability and refinement of designs. Teachers agreed that the stages of DBL could be used to frame a language and roles for integration of arts and science.

Preparation for and enactment of the 2018 Festival

In 2018, after a successful "capabilities week" program based in the four school communities, staff agreed that the STEAM Festival should also be community-based. Each community has approximately 150 students across years 7-10 and 12 or 13 full time equivalent (FTE) teachers, with expertise in art, science, maths, English, humanities, and technology. Though some teachers had team-taught individual subjects, working together to support students in a problem-based approach was a novel learning experience. The goals of the 2018 Festival were to: (1) give students insight into links between the arts and sciences; (2) enable students to explore an idea over an extended period beyond traditional timetabling; (3) work within communities vertically across age groups, and (4) celebrate as a college with parents and the community.

In a series of workshops, teachers were familiarised with DBL principles and stages, and then designed a student booklet to guide design thinking and learning. Students were expected to record each step of their design process, including drawings or photographs and reflections. Preparation took place in science classes at every year level. After an introduction to design-thinking language and principles, students worked in teams to design, construct, and assess the efficacy of a bridge created using newspaper and masking tape, and tested for taking weight. Thus, by the start of the two-day Festival teachers and students were familiar with the language and process of design-based thinking.

In 2018, the Festival was community-based and, as a reflection of the increased time that would be needed to complete the design phases, it was held over three days: 21, 22 and 23 August. Teachers in each community collaborated to plan and enact the Festival, choosing a project for their students based on the broad theme of movement in air or water or on land. Each community chose a different context and developed their own sequence of activities. Together the teachers in each community chose how to respond to the theme and assembled necessary resources. Students negotiated their teams with teachers and were generally based in groups of 4-6. Some teacher teams introduced a competitive element into their projects to inspire perseverance. Project products included the construction of elastic powered vehicles (mouse trap racers), kites, self-powered boats, rockets, vertical gardens, marble runs and helium-powered blimps. Teachers acted as mentors and facilitators, conferring together to assist students as needed. The Festival concluded with an evening for families at which student teams displayed their design booklets and their constructions and demonstrated the movement of their machines. Teachers facilitated discussions with parents and brought their own families along to enjoy the evening.

Research methods

This study used a case study approach (Yin, 2009), focusing on qualitative data to identify and interpret teacher reflections about working together. Qualitative data included semi-structured individual and focus group interviews, notes of observations on planning and review sessions and program enactment over two years, and a staff survey.

A university researcher conducted two individual interviews with five key staff before and after the May 2017 and August 2018 Festivals. These interviews aimed to identify the extent of met or exceeded Festival expectations in each of these years. Interviewees included two arts teachers, two science teachers, and the principal. In March 2019 the researcher also conducted a focus group interview in preparation for the 2019 Festival with 4 Festival leaders who had all participated in the four years of the project. This interview aimed to identify teachers' long-term perspective on working together and the program's evolution. In comments from this interview, leaders will be referred to as

Teacher 1, 2, 3 and 4. Teacher 1 has taught both science and the arts and is currently a visual arts and media arts teacher. Teacher 2 is a visual arts and visual communication design teacher who led the design aspect of the Festival, Teacher 3 is a science teacher, and Teacher 4 teaches music.

In 2017-2018, university researchers also participated as observers and critical friends in planning and review sessions of the Festival by key teacher organisers. One outcome was to assist the organising teachers in devising a survey of staff perceptions to be completed after the 2018 Festival. Thirty-five teachers completed the survey. The researchers observed a review and interpretation of survey responses by two key organisers (Teacher 2 and Teacher 3) which contributed to planning for the 2019 program. Complementary data included two researchers' observation notes of the program enactment over two years (2017-2018) and student booklets used for assessment purposes. The researchers also attended and observed the family celebration evening during which the students' artefacts were displayed and students, together with their teachers, discussed their projects with their families. Here we draw mainly on the focus group teacher comments as indicative of their considered views of the program.

Based on relevant literature and the case study data, we address the following questions:

1. What did participant teachers learn about the rationale and value of the integration?
2. What were teacher insights into their own and colleagues' subjects and teaching methods, and the nature of required teamwork?
3. What were teachers' views about the value of DBL for integrating arts and science?
4. How did their learning affect teachers' attitudes to potential future program modifications?

Our discussion addresses the implications of our findings for other teachers planning to integrate these two disciplines.

We answered the research questions through reiterative data analyses. The researchers undertook independent analyses of interview transcripts and observation notes to identify inductively emergent themes. These themes were then analysed to determine emerging findings, with a member check undertaken with participant teachers to confirm the accuracy of claims. Relational agency was used as a theoretical lens to interpret teacher reflections on why and how they collaborated, and what they learnt about their own and other teachers' practices (Edwards, 2015).

Findings

1. Teacher learning about the rationale and value of the integration

Participant science and arts teachers considered this integration warranted on multiple pedagogical grounds. These included: (a) dissatisfaction with students' prior compartmentalised views of learning; (b) the need for subject learning to match out-of-school, integrated just-in-time learning; (c) the synergistic compatibility of content in both subjects; and (d) the need for a coherent curriculum that focused on promoting student inquiry for real-world problem-solving.

Teachers were dissatisfied with poor student subject engagement, with Teacher 2, a visual arts and communication design teacher, noting that "anything that is different enhances student learning". Teacher 3, a science teacher, recognised strong synergies between the subjects and the value of removing constraining subject boundaries:

> We teach things in isolation but that's not the way the world is. [For example] you can teach photography as an art or a science. It's a way to express yourself. You don't need to know the science behind photography or develop a good appreciation for art to understand the science behind it. But it has intrinsic value to understand both. As soon as you ask why is that picture blurry, why is the image upside down, why has the colour come out like this, why is there no colour, that's where the science comes in.

This justification covers multiple warrants for integration including subject complementarity, the scope for mutual enhancement, and recognition that scientific knowledge can prompt and extend expressive, aesthetic options. Teacher 3 also noted the artificiality of curricular boxes for student reasoning, problem-solving, and enjoyment in learning. In a year 8 science class he observed student capacity to respond aesthetically to a science experiment. The students boiled a purple cabbage and extracted the juice as a pH indicator. They then tested lemon juice, vinegar, and milk, observing the colour changes. The students then created a rainbow effect in a large test tube. "The real world is kids having fun with what they've learnt and applying it to create a new product".

Subject integration is here seen as enabling student creative meaningful applied activity, in ways that conventional science teaching ignores or suppresses. Integration, particularly where scientific knowledge is applied to solve a problem or heighten an expressive or functional effect, was perceived to enable both a wider student perspective on each subject and more sustained problem-solving engagement.

2. Teacher insights into their own and colleagues' subjects and teaching methods, and the nature of the required teamwork

Teacher-teaming across subjects using the design process changed teachers' perceptions of their own subjects, and expanded their knowledge of others' approaches. For example, Teacher 1, a visual and media arts teacher, noted how other teachers chose "areas that might need to be specifically taught, and areas you might allow students to experience without specific teaching". According to this teacher, "we enhance each other and we're collaborating with the kids." Teacher 3 commented that "working with teachers outside science you get a completely different perspective on the task". He explained that the lengthy design and refine phase was often absent in conducting science experiments, partly because of a content-crowded curriculum. Collaboration expanded ideas about ways to teach their own subject. Teacher 4, a music teacher, considered that "the thinking involved in ideating, where you have to suspend your judgement, is important whether you are composing melodies or writing lyrics".

The teachers saw the integration as having multiple positive effects on their understanding of potential flexibility in their own and colleagues' teaching practices. Researcher observations of the planning and trialling phase of student design work in each community confirmed that participant teachers were enacting this flexibility, supporting varied levels of student progress through targeted feedback to individuals and groups.

Participant teachers also reported favourably on the value of team-teaching in enhancing their own learning and engagement, a finding confirmed by the researchers' observations of extensive teacher collaboration before and during the project work, which entailed adjusting intended goals and strategies before and during the Festival. Teacher 1 found it empowering "when staff work together and have control over where they want to take it". He noted that "working with your peers is a great learning experience. You draw on each other's expertise and extend your own. It's very motivating". Learning to be inclusive and considering "where people are, their understandings, their feelings" was a noted positive of the community collaboration. Teacher 4 remarked on the mutual responsibility and the generosity he experienced in collaborating with others in his community.

> There's a sense of accountability. I don't want to let my colleague down if we've said we're going to do this together. I was out of my area of expertise but drew on the technology teachers' expertise. The generosity between colleagues was evident throughout their planning and teaching. It was that team effort of getting together after the first day and working out how to shape it differently to work better. We mould together, we flex, we change it and we go again. It's an organic process.

3. Teachers' views on the value of DBL for integrating arts and science

Participant teachers perceived multiple benefits in structuring the integration around DBL. These included (a) a strong roadmap to justify and organise the focus and steps of inquiry, and to flag the complementary roles of contributing subjects; (b) a shared language between teachers (and between teachers and students) for the integration goals, processes and success measures; and (c) deeper student learning that went beyond traditional subject-based learning. The following comments illustrate these interconnected themes.

Teacher 3 noted that "we have this structure in our heads, this design process that we're going to follow". Teacher 4 claimed that "having and developing a good understanding of the design process was the biggest learning in terms of content knowledge. For each stage, what is the teaching that needs to happen to get the kids to understand the problem - to ideate, to prototype? It's the thinking process". For Teacher 1 "the (design) process allows people to open up about what they understand". In commenting on the value of the stages, Teacher 4 noted that "the kids wanted to rush to the prototyping. The making of it. It was really important to work about thinking about what we do, who's it for, what's the purpose?"

The teachers also broadly agreed that the design process entailed deeper student learning. For Teacher 2, "the kids are busy and thinking they are working less, but they are actually gaining a deeper understanding and a deeper learning". Teacher 3 agreed: "it's about the depth of what you do, not the breadth. You get a much deeper understanding on the part of the kids". Contrasting the flexibility of the design process with a traditional science approach this science teacher also commented that DBL "shows we should have massive flexibility… The design process is circular. It's constantly revisiting, looking for improvements, asking questions and trying to answer them. That's what we should be doing in science".

4. Teacher views on further program modifications

A staff survey after the fourth Festival (2018) indicated high levels of positive responses to the Festival but also the need to link it further to the everyday curriculum. Participant teachers broadly agreed that successful integration required: (a) considerable planning time; (b) the willingness of all participant teachers to team in planning, enactment, and review; (c) the design process to focus inquiry; (d) the devolution of initiative on topics to teacher sub-groups; and (e) ongoing school leadership support. The teachers also learnt about time constraints of the three-day Festival preventing students from completing every phase of the design process.

Achieving quality in disciplinary inputs into project designs was seen as a challenge. Teacher 3 expressed concern about the modest amount of science content in some projects, while Teacher 2 noted that the arts in a STEAM-based integration "pushes heavily towards design… not so much the fine arts although the craft side does come into it". She also thought the Festival was too limited to allow time for reflection about the successes of the integration. This teacher was already looking towards the 2019 Festival to extend the disciplinary collaboration "to see where our overlays are and how we can enhance each other".

All teachers perceived the value of increasing dedicated time to the Festival in 2019. An extended program of one week including preliminary field trips and guest speakers was planned for the first two days, to provide background information on topics in 2020 at the local Tech School. These included contemporary housing and sustainability, promoting eco-tourism, and the use of recreational parkland around the city. Staff in each community would be invited to decide on topics, and how they would plan and enact this with students. These topics align with Edwards' (2014) conditions for student inquiry meaningfulness.

A further extension of the program was planned for 2020. The principal intended to trial some integrated STEAM curricula, with topics and scale decided through consultation between subject and community leaders. Teacher 3 suggested that the most likely outcome would be a combination of community activities with a focus on design thinking. Teacher 2 considered that once integrated STEAM units of work into the everyday curriculum were established, "the timetable will evolve once again". This teacher recommended a cautious approach. "We might only come up with one unit that we trial. We'll have to see what we can actually manage when we're planning for a STEAM Festival at the same time as teaching our individual classes". Participant teachers were aware of many existing topic overlaps in the current siloed curriculum, such as "landforms in year 8 humanities, and tectonic plates in science" (Teacher 3), but were constrained by lack of time to develop a detailed action plan.

Discussion

Our findings indicate that teachers changed their orientation to their subject, teaching methods and teamwork, perceiving the rationale for and rewards of new practices. The science teachers learnt the value of a wider context and purpose for science inquiry, and the value of a more extended approach to formulating and addressing design issues. The arts teachers learnt the value of enhanced student understanding of how science knowledge can support and strengthen expressive purposes and problem-solving. In explaining why teamwork was effective in this case, we consider that teacher relational agency was crucial in shaping and sustaining this activity. This is evident in how teachers supported one another to design, enact and review the Festival, and deal with emerging and unexpected outcomes. Relational agency is evident also in the devolved negotiation of shared goals around the rationale and methods for integration, questions of program refinements and ongoing perceived ownership.

In the 2018 Festival, design-based learning provided a language, process and roles that enabled teachers to integrate arts and science in a practical project. Teachers gained insight into the relevance of the DBL process to their own subjects and the value of elevating the problem-solving approach above specific subject outcomes. They saw the benefits of students working together to share ideas, empathising with their audience, and learning from persevering with a challenge through multiple iterations to find a solution. While creative problem-solving is evident in both science and the arts (Arts at CERN, 2021; Eldred, 2016), the framing of complementary roles for each area in DBL was a productive first step in convincing teachers of the value and practicability of the integration.

Readers may consider the Melaleuca context unique, and the experimentation with new practices relatively limited, thus constraining possible insights for how to integrate arts and science in a different setting. While acknowledging this distinctiveness, and also noting that there is no single success formula, we claim that there are broad themes around challenges and opportunities in introducing this curricular change in other schools. The challenges include teacher readiness to participate, and then how to design, enact and review outcomes. As noted already, this curricular integration is predicated on new larger purposes and methods for learning in both subjects, and therefore deeply changes what counts as teacher subject expertise.

Enactment challenges include teacher teamwork and negotiation around key conceptual foci for topics or themes or artefacts, choice and use of relevant material and symbolic resources, and division of teacher labour in how learning is organised and assessed. In this case study, a thematic focus entailed conceptual learning and artefact production, thus integrating the three features noted by Turrka, et al. (2017) as the main ways science and arts have been linked in the past. The challenges of review include developing participant agreement about transitional preferences for the next phase of innovation, achieved in this case through extensive consultation and ownership by participants. Changing habituated teacher practices and the traditional organisation of curricular time and space are never straightforward, as noted in the teacher comments, but our case study shows one pathway forward.

There is still more to be learnt about how teachers conceptualise, support and assess student interdisciplinary learning, focusing on student learning about problem-solving processes (Hardiman & JohnBull, 2019), and the potential for how an aesthetics focus can change the languages of science (Tytler et al., 2020). However, our case study indicates that the participant teachers' extended exposure to experiencing this integration has made them more receptive to broader and inclusive perspectives about their own and others' teaching.

Concluding remarks

As noted in the literature on cooperative work between scientists and artists, these partnerships are mutually valued because they enlarge and enliven the work of those who participate. The participant teachers' comments in this study, based on four years of experience with a school-based version of this integration, echo this effect in their positive sense of curricular renewal for both themselves and their colleagues, as well as multiple student benefits.

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