Integrating Technology in STEM with Integrity: Avoiding the Mucky Brown Paint

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Abstract

This chapter explores and discusses a range of issues associated with the integration of science, technology, engineering and maths in the classroom. It will argue for an approach that enables authentic and appropriate representation of each discipline and the ways in which approaches can be students centred. The main implication of this approach for technology is that it puts it centre stage as student work towards the development of a technological artefact to meet an identified need or opportunity. Disciplines must be considered and specifically taught to develop skills and knowledge required by the students to reach their intended goal- a successful outcome to their technological practice. However, if purposeful teaching fails to occur students find themselves busy but not necessarily learning to their potential in the STEM disciplines.

Key Words

Integration, multidisciplinary, interdisciplinary, transdisciplinary, curriculum integrity

Introduction

In Chapter 2 Lee introduces us to the rationale and theory that underpins integration and in Chapter 7 Hacker outlines the integrated nature of STEM education through a number of possible models. The purpose of this chapter is to highlight a number of specific approaches used to integrate STEM subjects in the compulsory schooling sector (Grades K-12, Years 1-13) and to identify and discuss potential issues that can occur with integration in this sector. In the writing of this chapter, I draw on my personal experiences as a trained teacher with 25 years of experience in teaching and researching technology education in the initial teacher education sector.

Integration occurs when a number of different subjects or academic disciplines are taught through a project or learning task. The tasks should be designed to facilitate the development and application of knowledge through authentic contexts. STEM is learning to solve issues and problems and designing and creating artefacts (products and systems) by drawing on and integrating knowledge from science, technology engineering and mathematics disciplines.

How and why integration occurs and what form integration takes varies. Variations occur for a number of reasons and may be based on people's perceptions and understanding of technology, technology education, their competence in other contributing disciplines, and/or the nature of integration. When teachers do not have sound content knowledge of the disciplines involved students' learning can be compromised. Much of the literature identified discusses the nature or approaches to integration in research (Menken & Keestra, 2016; Pohl et al., 2017; Stember, 1991; Wohl, 1955).

The rationale for subject integration is strong. It can facilitate the development of meaningful programmes of work for students by increasing the relevance of learning and situating theoretical learning in authentic and relevant contexts. This approach is known to increase motivation and the value of learning (Bellanca & Brandt, 2010; Fox-Turnbull, 2003; Hill, 2017; Roberts et al., 2018) and to situate discipline learning in relation to other disciplines and the lives of learners (Pitt, 2017). Integration can also decrease unnecessary duplication across disciplines. For example, let us take the scientific concept of 'fair testing'. In a non-integrated environment, students are taught to undertake a fair test in science to complete an experiment task set for them. In technology, students are taught how to test a range of fabrics for durability and need to be taught how to do this so that only one variable is changed in each round of testing. In an integrated environment with a carefully planned programme, these lessons could have been combined into one with identified learning outcomes for both science and technology thus saving precious time for further learning. Unnecessary duplication can be decreased as students work within authentic projects to develop critical conceptual knowledge related to the 'big understandings' also known as core concepts, principles and theories that serve as a focus for learning, leading to enduring understandings central to disciplines and transferable to new situations (Gilbert, 2005; Murdoch & Hornsby, 2003).

In the school curriculum teachers and principals are often frustrated by a crowded curriculum. Schools are under constant pressure to keep pace with change and are frequently required to add new content to what they teach (OECD, 2020). This expansion puts pressure on education systems and teachers alike. Such pressure increases the temptation to 'cover lots with little depth'.

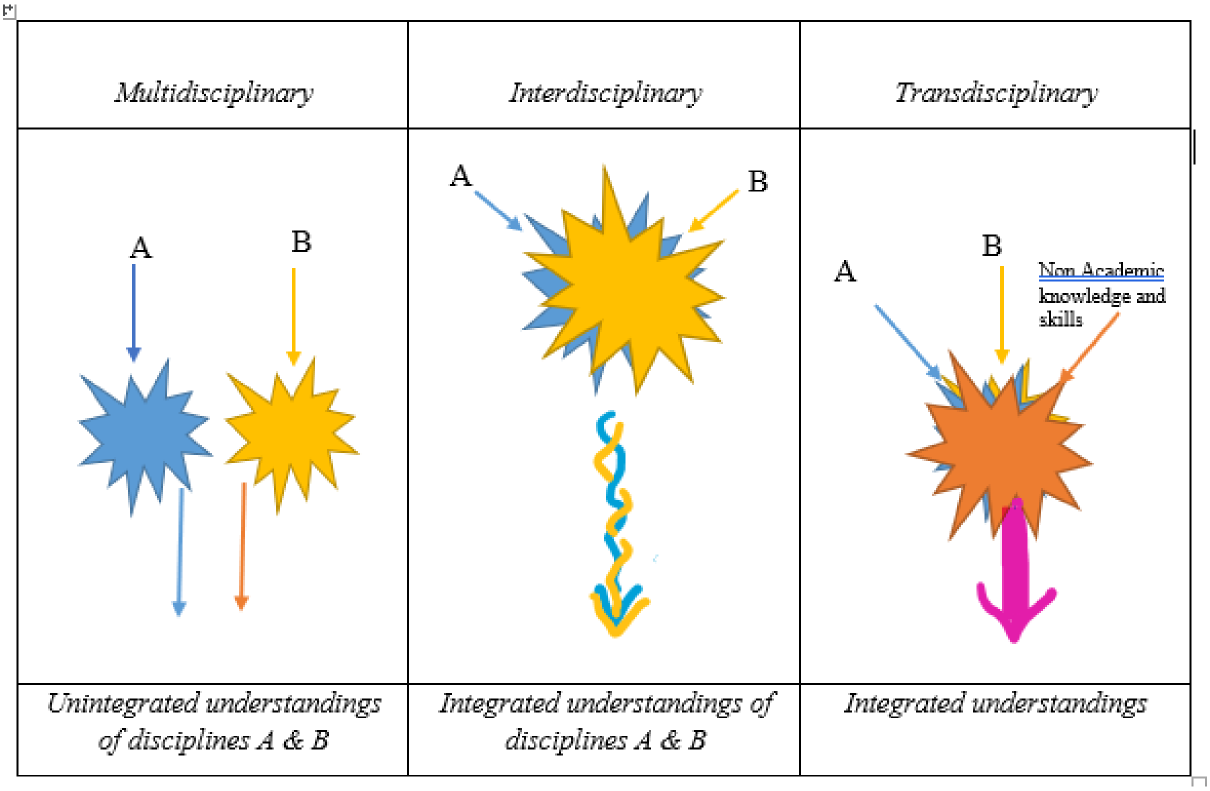
A well-managed curriculum focuses on 'big understandings' or conceptual ideas implemented using an integrated approach to teaching and learning and can offer a more authentic and motivational solution to the issue of overcrowding (Bellanca & Brandt, 2010; OECD, 2020). For example, recently I have been working on a project related to teaching junior children, aged 5-6 years, many of whom identify as Māori, the sequencing aspect of computational thinking as a part of digital technologies situated within technology education in The New Zealand Curriculum (Ministry of Education, 2017). The 'big understanding' for this unit is whakapapa- a Māori term meaning to recite in proper order. Māori use the concept of whakapapa to recite their genealogies and legends. Reciting *whakapapa* is central to all Māori institutions and an important skill that reflects the importance of genealogies in Māori society in terms of leadership, kinship and status.

The concept of sequencing is critical to computer programming and mathematics. Rather than teachers teaching sequencing in mathematics and then again in technology they will be taught through the big understanding of whakapapa the importance of order and sequence, with the ultimate goal of developing an online 'tour of their school' for newcomers. Thus, integration also has the potential to develop students' ability to transfer knowledge and skills across learning contexts.

What should integration look like in STEM when it upholds the integrity of technology education as described above? Imagine approaches to integration as a continuum, from simple to complex. There are three approaches on this continuum: multidisciplinary, interdisciplinary and transdisciplinary integration, with multidisciplinary integration as the simplest approach and transdisciplinary being the most complex. When deploying a multidisciplinary approach to integration, teaching and learning occur in a single theme, which is explored within a range of discrete disciplines. Discipline knowledge remains discrete with little opportunity given for students to transfer knowledge to new situations. The interdisciplinary approach is positioned in the middle of the continuum. It begins with a teacher-identified context, and students or groups of students identify an issue or problem and then design and develop possible solutions. At the other end of the continuum, a transdisciplinary approach engages students in authentic, often self-identified issues or problems, which students seek to solve by drawing on a range of discipline knowledge - as and when needed. Teachers guide their students to explore issues in depth and investigate, design and develop solutions. Using this approach, teachers can facilitate learning across a range of disciplines, often deliberately teaching curriculum knowledge on a 'just-in-time basis', to meet the emerging or future needs of their students.

Figure 1 illustrates each level with a different colour representing learning within disciplines. You will see in the right-hand 'transdisciplinary' column that the curricula A & B represented by blue and yellow are merged into green representing new learning and understanding through merged understandings from multiple learning areas as well as knowledge and skills of a non-academic nature such as collaboration or empathy.

Figure 1: Approaches to integration



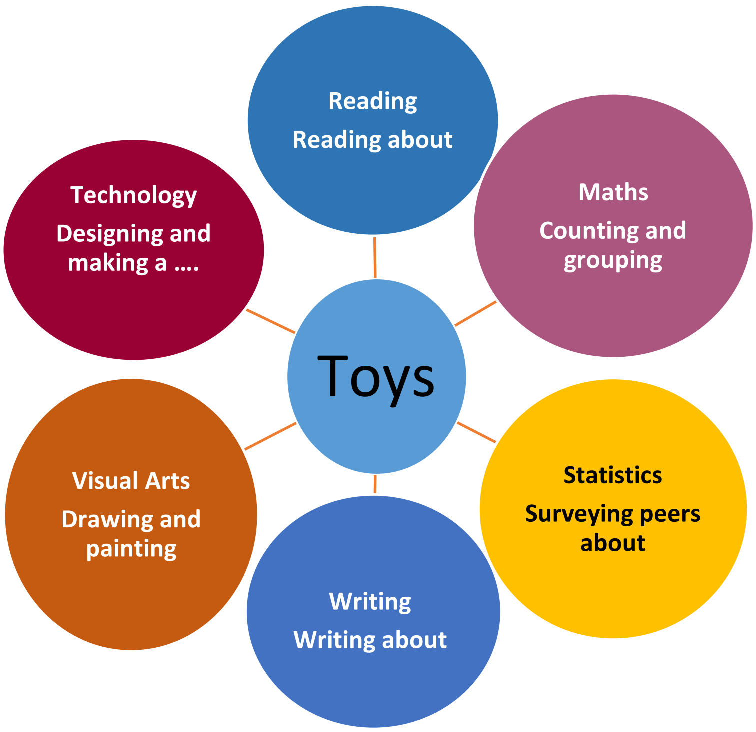
Each comes with its advantages and challenges. The following sections describe and illustrate each of the three approaches of integration and discuss some advantages and potential issues associated with each.

Multidisciplinary Integration

The multidisciplinary approach, also known as a thematic approach involves learning in discrete learning areas on the same theme or topic. In the traditional classrooms of the 19th and 20th centuries student learning was largely based on instruction where students were required to learn discrete facts in distinct subjects for ease of understanding or to pass a test. It was subsequently assumed that students could and would reassemble the school knowledge to apply to complex problems outside school when required. However, the school curricula failed to assist students in reassembling their learned facts into useful coherent bodies of knowledge thus the concept of curriculum integration and connecting school subjects gained momentum in the early 1990s (Wicklein & Schell, 1995).

The multidisciplinary approach is the lowest level of integration and typically involves teachers gathering resources, websites, and books that they use to plan many activities that are fun and engaging for students. This approach is called a thematic approach to teaching. When deploying a multidisciplinary approach to integration, teaching and learning occur in a single theme, which can be explored within a range of discrete disciplines. In primary school, units of work may include a range of activities and learning in different discrete curriculum areas, centred around a theme such as "toys" (Fox-Turnbull et al., 2021). Learning in this scenario could involve students reading about toys, writing about their favourite toy, drawing or painting pictures of toys, counting toys, surveying peers for their favourite toy, playing with toys and maybe even making toys as illustrated in Figure 2. In a multidisciplinary approach to integration apart from the context or 'topic' there are no further explicit connections across disciplines. In a secondary scenario, Wicklein and Schell (1995) discuss a multidisciplinary approach that used a technology survey tool to investigate a biological phenomenon with the assistance of the mathematics department for statistics interpretation. In this scenario, technology is reduced to the use of tools.

Figure 2: Multidisciplinary Approach to a Unit on Toys



There are a number of issues with this approach for students' learning and for technology education. The first is the lack of depth and understanding developed in each discipline. Units are not based on major concepts and provide little opportunity to transfer skills and understandings between different academic disciplines or into the students' world beyond school. Another issue is that students can become bored with the topic. An issue for technology education is that teachers, particularly in primary schools may believe they are integrating technology into their classroom programme or unit if their students undertake an activity on a digital device when in fact it is no more the integration of technology than using a pen or pencil as a writing tool. Another challenge with the multidisciplinary approach in technology is that students may be involved in designing and making an artefact but have no knowledge or understanding that they are engaged in technology practice, nor develop their understanding of the discrete components or aspects of the technology curriculum, nor how each contributes to technology practice. This becomes problematic for teachers who are required to progress students in technology. One further issue is that students may not have the opportunity to develop their understanding of the nature of technology, which in the New Zealand curriculum is a major aspect of learning in technology. Students may fail to understand the ethical, moral and environmental issues associated with their activity and how their technological outcome impacts and influences people and society because they are not encouraged to investigate potential social, ethical and environmental implications of the made outcome.

Interdisciplinary Integration

An interdisciplinary approach to teaching and learning is positioned in the middle of the continuum. When deploying this approach teachers identify the knowledge and skills needed to complete the intended project or to design and make a potential solution. It begins with a problem or issue that facilitates the linking of skills and understandings between different disciplines. The idea of interdisciplinary integration is not new. Wohl (1955) stated that interdisciplinary integration is a reciprocal interchange of ideas and information between two specialities. Wohl gives us some insight into early ideas of the nature of interdisciplinary integration and although he writes within the context of interdisciplinary research at the tertiary level there are a number of critical ideas with equal applicability to the integration of technology, engineering, maths and science in STEM education today. Interdisciplinary integration in the early days had its critics and its champions. Early supporters suggested that it was best when it arose spontaneously, rather than when contrived. The creation of formal organisation and legislation for interdisciplinary integration between disciplines did not produce effective conversations between disciplines.

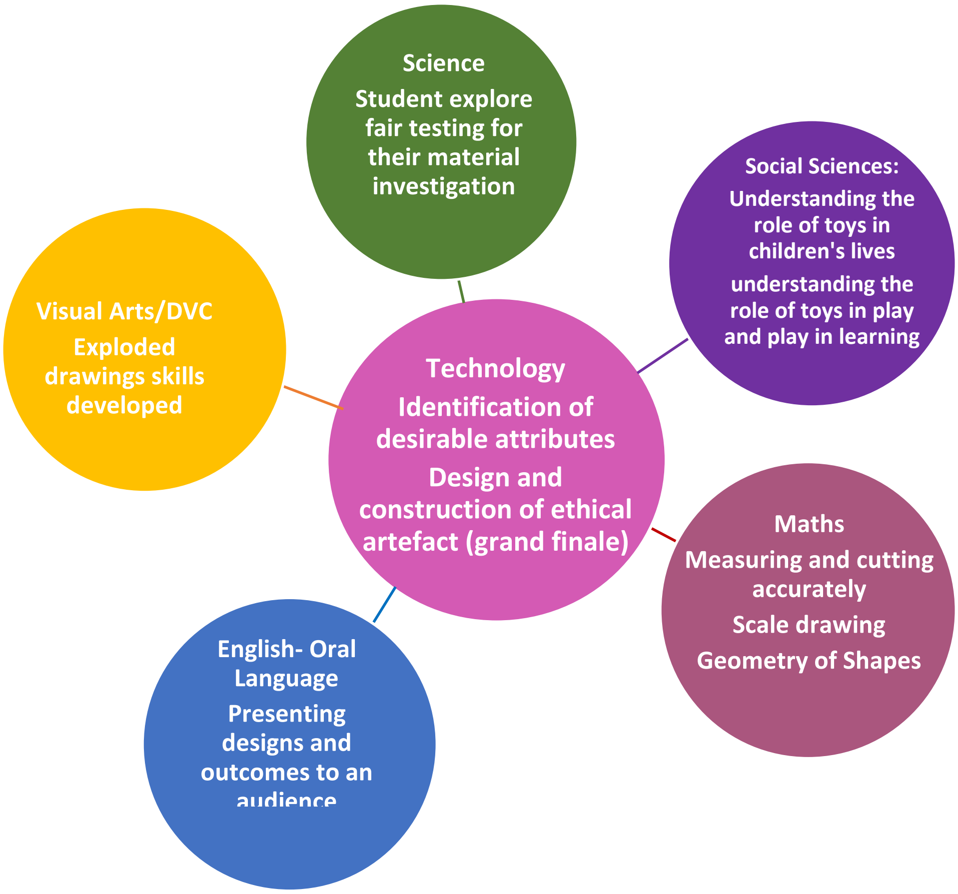
Stember (1991) identified a three-pronged argument for interdisciplinary integration: intellectual- the bringing together of academic knowledge from relevant disciplines; practical- a range of practical skills required to develop a potential solution, and pedagogical- a teaching approach that is a mix of specific teaching episodes, inquiry and investigation and needs-based or 'just-in-time teaching'. All three are equally applicable today. Motivation for interdisciplinary integration must be intrinsic. It is not unusual for the critics of interdisciplinary integration to suggest that its supporters aim to abolish discipline divisions, however, this is not the case. Interdisciplinary integration cannot occur without the necessary contributing specialisations. Synthesis is not automatic nor spontaneous but it must involve joint action by specialists. Interdisciplinary integration needs a commitment to work together collaboratively (Menken et al., 2016).

In the school context interdisciplinary projects offer students more than one perspective on the same subject. It may begin with a 'big understanding' that threads and guides students' learning. After exploration and investigation, students or groups of students identify more specific issues or problems within the given context and then design and develop possible solutions. STEM education should reflect the working world within which many parameters constantly change such as cost, materials, time availability and cultural values. Creating an interdisciplinary approach is an almost natural way to solve complex STEM-related problems (Klaassen, 2018). In this approach, there is an emphasis on students' needs and making meaningful connections between the curriculum and their lives. The inter-relationship of important concepts is explicit, as are the cross-curricular skills such as the key competencies (Fox-Turnbull et al., 2021).

In the classroom, units of work typically start with an issue that will contribute to a broader programme of work to develop an enduring understanding transferrable to other contexts. Students then research and identify a specific issue and need within the given context, explore, design and develop a solution, often presented to an audience at the end of the unit as a 'grand finale'. When planning an interdisciplinary approach to curriculum integration, teachers consider and identify specific skills and knowledge from a range of disciplines. The knowledge and skills identified are deemed as necessary for the students to successfully complete and present their project 'grand finale'. Students understand what and why they are learning, as it all relates to their current study.

Technology education lends itself to this approach as it allows students to make enterprising use of technological academic and practical knowledge and skills, together with those of other disciplines. Graphics and other forms of visual representation offer important tools for the exploration and communication of design ideas. Skills and knowledge from other areas such as Science, Maths, English, Arts and Social Studies also be authentically engaged. Again, we use the context of toys to illustrate this approach (Figure 3). The teacher takes the students on a visit to a local playcentre that is struggling for resources. The students observe and talk to children and staff at the centre, thus identifying their shortage of toys. Back at school students decided to design and make toys for the playcentre. In order for the students to be successful the teacher identified a range of skills and knowledge needed. These include understanding the role and function of toys, drawing designs, identifying and investigating the nature and properties of suitable materials, measuring, cutting and joining materials, understanding what makes toys attractive to the children and constructing toys from drawings to meet identified attributes. A big understanding for a unit such as this could be the 'educational value of play' or 'helping others'. It is important that these are identified by teachers well in advance and are selected with the needs of the students at the forefront of decision-making. Once identified it should drive learning and action, and be evident in the classroom conversation.

Figure 3: Interdisciplinary Approach to an Inquiry on Toys



This approach reflects the belief that the construction of knowledge and active involvement is essential for effective learning (Blythe, 1998; Kuhlthau et al., 2007; Murdoch, 2004). Within this approach, students' learning is guided and systematic with learning proceeding through a number of teaching/learning phases similar to that of guided inquiry. It is very different from 'open' discovery learning as teachers have a major and continuing responsibility to structure activities sequenced to maximize the skill development and thinking processes of their learners (Fox-Turnbull et al., 2021). This approach involves students developing deep learning through the process of self-motivated inquiry developing their 'big understandings' about the world and how it functions. It is centred on both process and content, with students taking considerable ownership and responsibility for their learning and 'grand finale' projects.

One issue is that the initial problems to be investigated and solved can be ill-defined and vague (Wohl, 1955). Another issue with this approach, especially in the classroom is that sometimes learning and activities are not structured nor targeted. Students may be left to their own devices with very little specific teaching in all or some of the necessary disciplines (Fox-Turnbull et al., 2021). This issue is exacerbated when teachers do not have comprehensive curriculum and pedagogical content knowledge, meaning some opportunities for learning specific skills, and knowledge may be missed. Discrete curriculum knowledge can be in danger of disappearing. In such situations, students may be very busy and having fun making their 'grand finale', but without focus on curriculum content or process knowledge, the quality of students' learning and the intended outcomes may be diminished. 'Mucky Brown Paint Syndrome' is a term used to describe this phenomenon (Fox-Turnbull, 2012). Imagine each discipline represented by a different coloured paint. When taught in a planned and structured manner using an interdisciplinary approach the teacher will facilitate learning in a range of disciplines to enable students to learn and deploy specific knowledge and skills to assist them with their project. Each discipline, while remaining discrete, contributes to the students' ability to develop a quality outcome or 'grand finale'. Imagine vibrant swirls of colour as portrayed in Figure 4), with each maintaining its integrity while enhancing and supporting its neighbour. However, if learning is not discrete and clearly articulated to the students, colours (disciplines) blend, and lose identity, with mucky brown paint emerging as illustrated in Figure 5. This means that although students are engaged in a range of activities, they are not necessarily aware of the disciplinarity of the knowledge and skills they are learning which may become an issue as they progress through their studies and are required to be aware of and draw on knowledge and skills from specific disciplines.

Figure 4: Merging of Discipline Skills and Knowledge (Paint) with Integrity

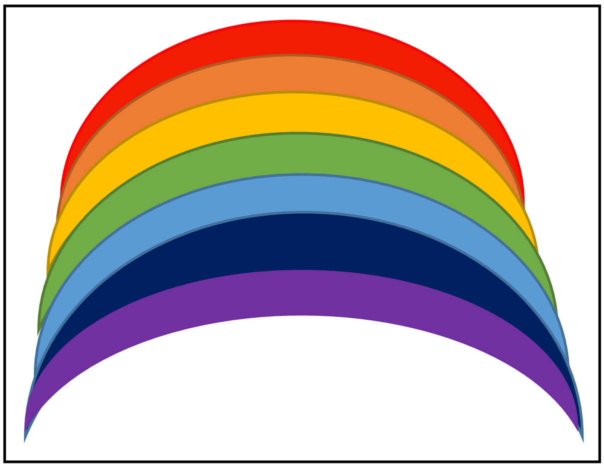
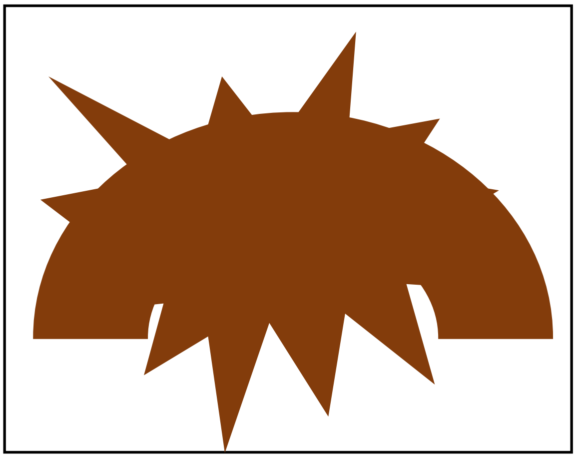


Figure 5: Merging of Discipline Skills and Knowledge (Paint) without Integrity



Interdisciplinary integration is the most relevant approach to the integration of STEM subjects in mainstream education. STEM integration using an interdisciplinary approach supports learning as the brain seeks patterns, meaning and connectedness. To avoid 'Mucky Brown Paint Syndrome' within STEM the integrity of each discipline must be maintained within projects and teachers must have strong content and pedagogical content knowledge in all four disciplines or work in teams of discipline experts to ensure that their programme planning and teaching makes content knowledge and connections obvious to their students.

Transdisciplinary Integration

At the other end of the curriculum integration continuum is the transdisciplinary approach within which students come across a range of curriculum areas appropriate to real-life contexts. It aims to facilitate learning processes between science and society. Transdisciplinarity is a means to bridge between a Western way of thinking and more holistic forms of indigenous knowing that do not separate scientific and spiritual thinking. To be truly transdisciplinary there must be an intention for improvement in the situation of the societal problem identified at the outset of the project. Artefacts must be designed and produced and there must be mutual and transformational learning for both learners and practitioners about the societal problem (Jahn et al., 2012), similar to that illustrated in Figure 5.

A transdisciplinary approach engages students in authentic, often self-identified issues or problems. Students seek to solve problems by drawing on a range of relevant knowledge and skills- as and when needed. In this approach, students direct their own learning and with that gain additional social skills and a deeper understanding of their world and the way it works (Zimmerman, 1990). Using this approach, teachers can facilitate learning across a range of disciplines, often deliberately teaching curriculum knowledge on a 'just-in-time basis', to meet the emerging or current needs of their students either individually or in small groups. Typically, when a study begins, the community becomes the classroom and learning involves real-life problem-solving. Student's learning is self-directed and they may work as individuals or in small interest groups. This approach is an example of full and more complex curriculum integration and underpins the philosophy of teaching evident in a range of schools alternative to the mainstream, such as Christchurch's Ao Tawhiti Unlimited Discovery School (Fox-Turnbull et al., 2021). Again, we illustrate this approach through the context of toys (Figure 6). This starts with a student arriving at school upset about the fact so many toys are made of unfixable plastic and have to be thrown away when broken. The student knows that plastic can be harmful to the environment and asks the teacher if the class or a small group can work together to develop a solution to the issue. A thorough investigation of the issue begins by identifying and researching a range of relevant questions before determining a possible solution- the development of a range of environmentally friendly toys.

This is an exciting approach to learning but does come with challenges. Students do not work in specifically identified disciplines, but instead develop the knowledge and skills required to solve their issues. This becomes problematic for teachers when they are required to report on students' learning in discrete disciplines or prepare students for formalised discipline-based assessment. Tracking students' learning in all disciplines is also an issue for teachers as students within one class may be working on a range of issues at any one time and learning in different disciplinary contexts. There is also a danger that the students themselves are unaware of discrete discipline knowledge when at some stage they must select or identify specific 'subjects' for secondary assessment or further study for example. However, given the school-based and life experiences students assimilate by the time they select pathways for further study, it is likely that many will have little difficulty in determining programmes of potential interest and be rich in disciplinary knowledge.

Figure 6: Transdisciplinary Approach with Issue about plastic toys

Conclusion -Avoiding the Mucky Brown Paint: Implications for the Classroom

In summary the three approaches to integration discussed in this chapter have distinctive characteristics and offer students considerably different learning experiences. Table 1 offers a summary of the key ideas of each approach.

Table 1: Summary of the Characteristics of three Approaches to Integration

Multidisciplinary	Interdisciplinary	Transdisciplinary
Topic identified by teacher and same across disciplines.	Context is identified by the teacher in most cases until senior secondary. Learning can occur across topics and varies as long as skills and knowledge work towards developing the final intended outcome or 'grand finale'.	Context is driven by students to make a meaningful difference in the world.

Perspectives used to illustrate a theme	Several disciplines contribute to the solution of a problem. Differences in disciplinary knowledge are privileged.	Involves collaboration with non-academic stakeholders
Revisiting major concepts, not a core instructional goal	Several disciplines contribute to solving a problem	Technology is seen as the central agent in STEM integration.
Students are taught in discrete disciplines and are not taught knowledge transfer	Students are aware of the disciplines they are working across and are encouraged to transfer knowledge and skills across disciplines	Students are not taught in disciplines. They develop the knowledge and skills required to solve their issue
Disciplinary interrelationships may not be apparent	Focus on disciplinary interrelationships is critical to success	Learning that knowledge and skills occur in discrete disciplines is incidental
Limited attention to learning transfer	Curriculum and instruction are intended to increase learners' coherence and transfer across and between disciplines	Unifying ideas revisited in multiple contexts to facilitate a more holistic understanding
Assessment discrete and progress easily monitored and reported	Assessment is discrete but monitoring can be difficult as students work across projects within one context	Formative and Self-assessment with focused feedback assist students to drive for success. Monitoring and reporting in discrete disciplines is very difficult
Students can become bored.	Students are likely engaged and motivated if the initial context piques students' interests.	Students are very engaged and motivated as they drive their own learning.

So what does this mean for technology education? Interdisciplinary and transdisciplinary approaches are integral parts of the technological innovation cycles and can bridge the gap between research, industry and education (Ehlen, 2015; Klaassen, 2018). We talk about the need for technology education to be holistic rather than fragmented. By holistic we mean the need for students to develop an understanding of the links within technological practice and to see how key ideas reoccur in different contexts rather than having a fragmented view of each part in the process. To develop this understanding, students need to be aware of the whole technology process and how the components link together and are best undertaken in situations authentic to practice. Thus, students are aware of what a technologist or team of technologists is involved in during technological development. This often means that technology is very comfortable as the central agent in STEM integration because students are aware of the authenticity of the disciplinary knowledge they draw on. For example, they learn how to speak in public because they need to present their ideas to the school's Board of Trustees or governing body or calculate the area of their designed garden to calculate the materials required.

In today's educational environment where senior secondary assessment processes and practices determine future pathways for students in discrete discipline areas, the interdisciplinary level of integration is most suited. It allows students, with the assistance of their teachers, to identify and draw on specific and relevant disciplinary knowledge for authentic purposes. In New Zealand, the Ministry of Education has signalled very clearly that technological activities, including digital technologies, must occur in authentic situations (Ministry of Education, 2017). This means that T in STEM is not only the use of digital devices or other technological tools. Students must be embedded in authentic technological contexts to develop and practise skills and develop knowledge that is contextualised and integrated with a range of other discrete disciplines, for reasons that are real and make sense to them. There are implications here for the direction of professional development for primary and STEM teachers. Teachers need to be informed about technological practice and the technological areas or contexts and make links with authentic practice facilitating sound decision-making for their students.

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