Chapter 7
Stimulating Creativity and Critical Thinking in Integrated STEM Education: The Contribution of Out-of-School Activities

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Abstract This chapter describes how effective integrated curricula with an out-of-school component encourage students to develop their STEM understanding and skills in at least three ways. First, by testing the disciplinary knowledge they have learned in real-world, authentic contexts, students come to appreciate that good understanding requires balance; that disciplinary knowledge must be complemented with interdisciplinary or integrated knowledge. Second, by investigating issues outside of the classroom, students experience a sense of the "bigger picture", enabling them to see how what they have learned can contribute to STEM-related issues beyond their classroom. Third, when students work on issues that are important to the local community and face matters relating to social values and diversity, they have opportunities to develop their senses of social and ecojustice. Three research-based examples of integrated STEM learning are analysed in terms of the OECD dimensions of creativity and critical thinking – inquiring, imagining, doing, reflecting – to illustrate how guiding students to interact with local, place-based, or community issues can benefit not only their creativity and critical thinking, but enhance their skills of communication and collaboration.

Keywords STEM integrated curriculum · Creativity · Critical thinking · Out-of-school

In thinking about the three foci for this volume – STEM (science, technology, engineering, and mathematics), creativity, and critical thinking – I felt a sense of déjà vu and wondered why. Gradually I realised that my ideas about the outcomes of education, particularly STEM education, have coalesced around two principles: the purpose of school education and the critical importance of experience. The first of these

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principles grew from my teacher training when I was required to read Ralph Tyler's seminal exploration of curriculum (Tyler, 1949). Tyler asked four questions about curriculum and instruction in school education. "What educational purposes should the school seek to attain?" "How can learning experiences be selected which are likely to be useful in attaining these objectives?" "How can learning experiences be organised for effective instruction?" and "How can the effectiveness of learning experiences be evaluated?" These questions are sequential and in planning any curriculum the first question must be the starting point. John Wallace, Grady Venville, and I explored this question in depth, asserting "that schools should seek to provide students with the knowledge that prepares them to be responsible adults and sensible citizens in a rapidly changing global environment" (Rennie et al., 2012, p. 120). We used the term "knowledge" holistically to include the accompanying skills and capabilities. From our exploration of how integrated curriculum can contribute to this kind of knowledge – the "knowledge that counts" – we proposed a "Worldly Perspective [as] the crux to understanding the two significant dimensions of curriculum – the balance between disciplinary knowledge and integrated knowledge, and the connection between local types of knowledge and global types of knowledge" (p. 120). We emphasised that the particular curriculum context would determine the point of balance and degree of connection, and argued that offering "a curriculum that achieves both balance and connection" has the best chance of providing "students with powerful knowledge to negotiate and improve the global community in which they live" (p. 120).

The second of these principles, the importance of experience, was crystallised by an unknowingly insightful observation by our daughter Susan, who, at the age of 8 years, announced one night at the dinner table: "Today in our music class, the teacher asked some of us to sigh. But I didn't know what to do." Her older sister was astonished. "How could you not know how to sigh?" she asked, "Trixie Beldon [the central character in a series of their story books] sighs all the time!" Susan replied: "But I only *read* her sighing – I don't *see* her sighing." I used this anecdote three decades ago when asked to provide a personal summary of conference papers about gender, science and technology in primary and secondary schooling (Rennie, 1990). It illustrated perfectly the importance of actual, first-hand experience in learning science compared to the vicarious, second-hand experience of reading about it. I argued then, as I believe now, that "If pupils do not experience a meaning and a context for what they have the opportunity to learn, they are unlikely to learn it" (p. 191).

These two principles, the purpose of school education and the critical importance of experience, underpinned a statement I made at the 2008 conference of the Australasian Science Education Research Association when talking about promoting scientific and technological literacy through school-community links. I proposed that, if one goal of school education is scientific and technological literacy, then school science and technology should aim to give students a repertoire of knowledge and experiences that can be retrieved from memory to aid interpretation of new situations and provide direction for making decisions about them. I further argued that a powerful way to do this was to promote links between the school and community.

What was it about STEM, creativity, and critical thinking that triggered these memories? The explanation resides in my understanding of literacy in science and technology as fundamental to an education that prepares students for life after school. In the following sections I will overview the meanings of scientific and technological literacies then consider how they contribute to literacy in STEM and to the development of skills in creativity and critical thinking. This discussion will focus on science and technology, but in my mind the intelligent use of both is invariably intertwined with mathematics and, when artefacts or processes are involved, engineering. Next, three case studies of school students' learning in projects that involved out-of-school activities are described to illustrate the connections between integrated STEM, creativity and critical thinking. The chapter concludes with a summary of how school-community links benefit students' learning of knowledge and skills in an integrated STEM context.

7.1 Defining Scientific and Technological Literacies

The general goal of literacy in science and technology is the same as the goal of any literacy, including reading, writing, or using numbers. It is "to provide people with the tools to participate intelligently and thoughtfully in the world around them" (Pearson & Young, 2002, p. 3). For literacy in science and technology, some explanation is required about the tools people might use, and how intelligent and thoughtful participation might occur. Table 7.1 employs a framework suggested by Pearson and Young (2002) in the context of technological literacy to set out descriptions of

Table 7.1 Descriptions of Scientific and Technological Literacies (based on Rennie, 2003)

Dimension	Scientifically literate persons	Technologically literate persons
Knowledge	Are interested in and understand the world around them	Understand the designed world, its artefacts, systems, and the infrastructure to maintain them
Capability	Engage in the discourses of and about science	Have practical skills in using artefacts and fixing simple technical problems
	Are able to identify questions, investigate and draw evidence-based conclusions	Identify practical problems, design and test solutions and evaluate results
Ways of thinking and acting	Are sceptical and questioning of claims made by others about scientific matters,	Recognise risks, weigh costs and benefits associated with new technologies
		Evaluate, select and safely use products appropriate to their needs
	Make informed decisions about the environment and their own health and well-being	Contribute to decision-making about the development and use of technology in environmental and social contexts

scientific and technological literacies in three dimensions: knowledge, capability, and ways of thinking and acting. The descriptions themselves evolved in the following ways.

In a report to the Australian Government on the status and quality of school science education, Goodrum et al. (2001) argued that scientific literacy was central to quality teaching and learning. These authors offered a description of a scientifically literate person developed from a broad review of the contemporary literature, including Bybee (1997), Bybee and DeBoer (1994), Collins (1995), Fensham (1997), Jenkins (1997), Millar and Osborne (1998), the National Research Council (1996), and the OECD Program for International Student Assessment (OECD/PISA, 1999). This definition occupies the second column of Table 7.1.

Not long after the Goodrum et al. (2001) report was released, I was asked to assess the role of literacy in technology education. It seemed useful to compare and contrast it with the Goodrum et al. description of a scientifically literate person, and so describe a technologically literate person. I drew on reports from Barlex and Pitt (2000), Black and Harrison (1985, although their insightful analysis of science and technology in curriculum did not mention literacy), Jenkins (1997), Gardner, Penna, and Brass (1990), and Pearson and Young (2002) to propose the description in Column 3 of Table 7.1 (Rennie, 2003). The description of technology has close relationships with engineering (National Assessment Governing Board, 2014; Tang & Williams, 2018), and literacy in mathematics in the STEM context is often reduced to skills in numeracy (EU Skills Panorama, 2015).

The descriptions in Table 7.1 have proved useful in many contexts, most recently in an empirically-based exploration of adults' needs for literacy in science and technology (Rennie, Stocklmayer & Gilbert, 2019). In this exploration we also scrutinised the relevance of STEM, an acronym of many meanings that has often been used as a term of convenience for any one, some, or all of its component disciplines. What is its relevance here?

7.2 STEM, Creativity, and Critical Thinking

Other chapters in this volume address various aspects and meanings of STEM, but two STEM-related analyses are mentioned here to introduce STEM literacy and what are sometimes called STEM skills. This will lead us to a consideration of creativity and critical thinking.

Tang and Williams (2018) reviewed the meanings of the term "STEM literacy", together with recognised definitions of literacies in the separate STEM disciplines. They found three "similar trends and lines of inquiry in the way scientific, mathematical, technological/engineering literacies have been conceptualised" (p. 14). These were

- the creation, use and conversion of codified multimodal representations;
- the mastery of common visual resources such as annotated diagrams and geometric drawings;

- the application of cognitive and metacognitive strategies involving problem identification, planning, evaluation and self-monitoring. (p. 15)

These three trends or lines of inquiry are interrelated. While the first two have a particular focus on the communication and sharing of knowledge, all three necessitate the use of creative and critical thinking. Tang and Williams (2018) suggested that these three common trends could provide a basic – but limited – STEM literacy; "a holistic understanding of how concepts, processes and ways of thinking can be integrated and applied to the design of a solution to a real-world problem" (p. 18). However, these authors concluded that the differences among the separate disciplines in their disciplinary languages, cognitive processes, and epistemic practices limit its application, and thus a more complete conceptualisation of STEM literacy requires that these common trends be interwoven with the literacies of the separate STEM disciplines. This conclusion mirrors the argument for balance between disciplinary and interdisciplinary knowledge mentioned earlier as a means to ensure that students acquire "knowledge that counts" (Rennie et al., 2012).

We can reach a similar conclusion from another perspective by exploring what is meant by STEM skills. Siekmann and Korbel (2016) provided a review and analysis of STEM skills in the context of vocational education. Commenting on the different meanings that STEM skills would have for different groups (educators, STEM specialists, technologically proficient workers, and scientific and technologically literate citizens), Siekmann and Korbel acknowledged the difficulty of finding a common understanding. They suggested that STEM skills belong to a group of technical skills but "they overlap broadly with other skills groups such as generic and cognitive skills, as well as employability skills and the twenty-first century skills" (p. 45). They recommended against adopting the term "STEM skills"; instead it should be acknowledged "that STEM is an umbrella term" (p. 47) and that skills should be identified by their "the original definition or their category, for example, cognitive skills, foundational literacies, job-related technical skills etc." (p. 45). Siekmann and Korbel proposed that STEM skills be incorporated in a holistic skills framework, such as the Twenty-first Century Skills Framework.

The original Framework for twenty-first century Learning, developed in the United States, highlighted 18 different skills designed to be built into education standards, assessments, and professional development, but it was found to be too complex (National Education Association [NEA], n.d.). Four specific skills known as the "Four Cs" – creativity, critical thinking, communication, and collaboration – were agreed to be the most important and became the focus of education in many US states. Significantly, national educational bodies for arts, English, geography, languages, mathematics, science, and social studies, are affiliated with the Four Cs framework (NEA, n.d.). Clearly, creativity, critical thinking, communication, and collaboration are interdisciplinary skills, and this is a significant part of the argument I wish to make here.

These reviews concluded that STEM literacy and STEM skills are both umbrella terms, and both depend on the metacognitive skills of creativity and critical thinking. Here is where the sense of déjà vu kicked in. If the reader revisits Table 7.1 and peruses the descriptions of scientific and technological literate persons, it will become clear that such persons will be able to demonstrate creativity and critical thinking – no matter how these terms are defined – in the contexts of science and technology. Furthermore, the scientific and technologically literate people described in Table 7.1 will be demonstrating those skills as they participate in their day-to-day experiential world. It follows that if students are to develop these thinking skills in the context of STEM, in ways that will help them cope in later life as responsible adults and sensible citizens, they will need to practice these skills in contexts that take them outside of school.

The next sections of this chapter describe three examples of integrated STEM programmes that illustrate how students have been given opportunities to develop their creativity and critical thinking in school-community programmes. All three examples were part of larger funded projects focused on science or biotechnology but it will become obvious that all required the integration of the STEM disciplines. Creativity and critical thinking are discussed in detail elsewhere (see particularly Ellerton & Kelly, Chap. 2, this volume), but substance is given to their meaning here by using the OECD rubrics to support creativity and critical thinking in teaching and learning (Vincent-Lancrin, Chap. 3, this volume). Here, the essence of creativity is defined as "coming up with new ideas and solutions" and critical thinking as "questioning and evaluating ideas and solutions" (Vincent-Lancrin, Table 3.1). Consistent with the statements made by many curriculum authorities (see Corrigan, Pannizzon & Smith, Chap. 6, this volume), the OECD considers creativity and critical thinking to be different but closely related. For example, the Australian Curriculum describes creativity and critical thinking together with the key ideas of inquiring; generating ideas, possibilities and actions; reflecting on thinking processes; and analysing, synthesising, and evaluating reasoning procedures (Australian Curriculum Assessment and Reporting Authority [ACARA], n.d., p. 2/3). These key ideas are very similar to the OECD rubrics that provide descriptions of both creativity and critical thinking in four dimensions: imagining, enquiring, doing, and reflecting (Vincent-Lancrin, this volume). Succinct descriptions of these four dimensions can be proposed by synthesising across the OECD rubrics for creativity and critical thinking, as follows.

- Inquiring – identifying, collecting and organising information and potential approaches to problem solving;
- Imagining – generating and exploring ideas, possibilities and actions;
- Doing – creating, testing and justifying products and processes;
- Reflecting – synthesising reasoning and evaluating outcomes and procedures.

These dimensions will be used to guide analyses of three case studies. The first relates to the disposal of intractable waste and the second concerns poisonous tiger snakes[1] endemic to an urban wetland. Both were school-community projects based in primary schools. The third project involved seven students from different secondary schools who experienced a mentorship in biotechnology.

[1] Tiger snakes are a highly venomous species found in parts of Australia. They can be aggressive.

7.3 Case Study One: Disposal of Intractable Waste

The disposal of intractable waste project was part of the Science Awareness Raising Programme led by the Australian Science Teachers Association (ASTA) (Rennie & ASTA, 2003) with funding from the Australian Government's Department of Science, Education and Training. The purpose of the programme was "to promote greater understanding in the educational and broader community of why science is important, why time is spent on it in school and why scientific literacy is an important outcome of schooling" (p. viii). Seven projects across Australia were funded to field test a science awareness raising model developed by ASTA for schools to work with their community on a science-related issue of importance. The Western Australian project was based in three schools in a major rural city. The following description draws from the evaluation of the ASTA Science Awareness Raising Project (Rennie & ASTA, 2003) that reports details of the research design, data collection and analysis.

7.3.1 Context of the Project

Intractable wastes are unable to be recycled in a viable way, take considerable time to break down or are not easily destroyed, and need long-term management for community and environmental protection. At the time of the project, low-level radioactive and chemical wastes were buried in trenches at an Intractable Waste Facility at Mt. Walton, located 125 km from a major city in the goldfields of Western Australia. The facility was constructed in 1992 and is currently under care and maintenance, with no waste deposited since 2014. However, when the ASTA project began in 2002, the operating company was investigating the suitability of dumping high level radioactive waste, and this made the matter of intractable waste of considerable concern for the surrounding communities.

7.3.2 Overview of the Project Activities

Three schools undertook separate but related projects about intractable waste disposal. This case study focuses on one project involving two Year 6/7 classes (children aged 11–12 years) and their teachers. The overall aim was for students to work with community members and resources to investigate the impact of the Waste Facility on their local environment and the impact of future waste storage. The students would then inform the community about the environmental and safety considerations in moving and storing intractable waste, enabling the issues to be better understood on a broader scale.

The project was undertaken over two terms. Students began by exploring the issue of intractable waste, gathering information about the Mt. Walton site via internet and newspaper searches and interviews with stakeholders (Department of Mineral Resources, environmental and interest groups in the community) and resource people (from the museum, library, hospital, parents, and neighbours) by phone, fax, and email. They also surveyed community members about their understanding of waste disposal, particularly radio-active material; thus uncovering a range of myths and misunderstandings. Students collated and organised their findings on display boards in their classrooms. These inquiry activities served to build students' understanding of the nature of intractable waste, identify the contentious issues that underpin the problems of disposal, and try to envisage ways forward.

In the second term, students created "expert groups" to undertake more intense investigations into the critical aspects of waste disposal they had identified. Students arranged guest speakers on specific topics, visited the road leading to Mt. Walton to check its safety for transporting waste, and followed up some media reports about waste storage. They investigated the geological stability of the site of the facility and alternative uses of the waste. The costs and benefits of disposing of intractable waste were weighed up and examined together with the roles and responsibilities of federal, state, and local governments.

Progress was documented on a large display board in the main school hall to raise awareness of other students and teachers, and parents who visited the school. A Communications Officer (funded by the project) assisted students to develop the displays and provided weekly updates to inform the school community. To help raise awareness in the community, student spokespersons were interviewed on local talk-back radio and featured in stories in the newspaper. To consolidate the project outcomes, students decided to prepare an information brochure about the Intractable Waste Facility. It was checked by the Department of Environmental Protection and then distributed to the community via the school and local shopping centre.

7.3.3 Outcomes of the Intractable Waste Project

From their investigations, students developed a "big picture" perspective of the Mt. Walton Waste Facility. In terms of knowledge, students learned what intractable waste is, how it can be stored safely, and the potential environmental impact. They were exposed to different points of view from various groups, to the ethical and political responsibilities of the various levels of government and they debated relevant sensitive moral, ethical, and environmental issues. Students developed and practised skills in gathering information and assessing its credibility, organising, synthesising, and critically analysing their findings, generating ideas for the next steps and reflecting on and evaluating their progress. They learned about design relating to their poster boards, preparation and printing of the brochure, public speaking, working collaboratively, goal setting, and time management. The knowledge, skills, and understanding the children developed were merged seamlessly in an integrated STEM project in which science and technology overlapped with art, English language, health education, mathematics, and social studies.

Teachers and parents reported that motivation remained high throughout the project. Parents learned about intractable waste and the Mt. Walton Facility via their children, displays in the school and the brochure. The wider community read newspaper stories or heard the children on radio. The project evaluation revealed that students' attempts to communicate with the local community were successful; more people knew about the facility and had an increased understanding of its purpose and operation after the project than before.

7.4 Case Study Two: Living with Tiger Snakes

"Living with Tiger Snakes" was one of 24 projects across Australia in the School Community and Industry partnerships in science (SCIps) programme (ASTA, 2005), managed by the Australian Science Teachers Association (ASTA) and funded by the Australian Government. The SCIps programme aimed to forge connections between schools, their communities and industry, to enable them to collaborate on local, science-related community issues, promote scientific literacy in the school and community and enrich students' science education through project-based learning based in the students' experiential world. "Living with Tiger Snakes" was a Western Australian project involving a wildlife centre as the industry partner and a nearby primary school with its community. The available funding was used to support the Wildlife Centre Manager's time and transport for the students between the school and the Centre. The outline below is drawn from the project evaluation and details of the research design can be found in Evans, Koul, and Rennie (2007), who described the project from an environmental perspective, and Koul and Evans (2012), who analysed it as a case study of curriculum integration with a community focus.

7.4.1 Context of the Project

The Wildlife Centre overlooks a large wetland area that includes a lake, and is a significant urban habitat for highly venomous tiger snakes (*Notechis scutatus occidentalis*) that are endemic to Australia. The venom contains neurotoxins, procoagulants, and myotoxins, the effects of which can lead to renal and respiratory failure. All bites must be considered urgent and potentially lethal, and antivenom therapy is usually required. The snakes feed mainly on frogs and are important predators in an increasingly fragile wetland ecosystem. In summer, the snakes frequently invade the surrounding properties and are often killed by householders, thus threatening the wetland's biodiversity and its ecological balance. A response more appropriate than indiscriminate slaughter is to arrange for the invading snake to be "relocated", something the Centre Manager is frequently asked to do. The Living with Tiger Snakes project was designed by the Centre Manager to address the community's fear and ignorance about tiger snakes by promoting understanding of snake behaviour; precautionary and safety issues, and deterrent measures that should be taken; and appreciation of the role of tiger snakes in the ecosystem and the importance of preserving wetland diversity.

7.4.2 Overview of the Project Activities

The Centre Manager liaised with the lead teacher at a small school located in the vicinity of the lake to plan an integrated environmental programme for the school's two classes of Year 4–7 children (45 children aged 9–12 years) and their teachers. About half of the 6-week project was carried out at the Wildlife Centre and half at school. The Centre Manager led activities including nature walks around the wetland, and dipping in the lake to learn about biodiversity and lake ecology. He visited the school for lessons on food chains and food webs in the lake. A central theme addressed behavioural precautions, how to deal with snakes calmly and what to do if bitten. During the introductory and concluding sessions of the programme, snake experts brought live snakes to the Centre that the children could handle, and tiger snakes that they could look at (but not handle).

With their teachers back at school, students consolidated their learning about snake biology, behaviour, and first aid procedures. They designed a survey and then interviewed 190 community members about their attitudes and knowledge about snakes, then collated, analysed, and graphed their results. To help inform the community about snake behaviour and safety, they prepared posters, wallet cards, badges, and signage for the lake perimeter. Groups of students designed and made dioramas of snake habitats and snake unfriendly gardens. Others built displays to illustrate food webs and food pyramids. Students' in-group conversations revealed how they developed and tested their ideas to find the best ways to build their models and decide what information was most important to put on their posters.

The project focused on educating the students about tiger snakes and, through them, educating the community. To achieve this aim, the project culminated in an evening event at the Wildlife Centre, attended by about 100 family and other community members. Every child was involved in a variety of activities, including acting out role plays to demonstrate first aid in case of snake bite, power point presentations of information they had learned about tiger snakes and their survey results, and displaying and explaining their dioramas, posters, and other interpretative materials, all designed to communicate what they had learned about coping safely with tiger snakes.

7.4.3 *Outcomes of the Living with Tiger Snakes Project*

Teachers described how this integrated project contributed to all of the learning areas in the mandated state curriculum: Students learned science knowledge specific to tiger snakes, the interdependence of organisms, the environment, food chains and food webs; in technology they used the internet, power point presentations, designed and made models; in mathematics they critically analysed their survey data and worked out the best way to represent the results; in English language, children created scripts for their role plays and made verbal presentations; acting in role plays, making posters, badges, dioramas, and using computer graphics all contributed to the arts; in health and physical education, students learned about first aid and the precautions to take while bush walking. In social studies, active citizenship was demonstrated through their participation in survey data collection and presentation at the community night, contributing to a snake-safe neighbourhood. In addition, children explored the curriculum core values of social, civic, and environmental responsibility.

Tiger snakes were a recognised community issue and attendees at the evening event saw and heard a great deal about tiger snakes and safety presented in a variety of ways. Children's excitement during their presentations was a feature. One child who, in the introductory session, refused to even look at the snakes brought by the visiting herpetologists, came forward in the final session and was able to stroke a snake. Informal conversations with family members emphasised their children's excitement, interest, and learning in the topic, particularly in regard to the preservation of tiger snakes.

7.5 Case Study Three: Biotechnology Ambassadors

The World Biotech Tour (WBT) was a three-year initiative designed to promote a greater understanding of biotechnology through public outreach programmes led by science centres and museums. The WBT was coordinated by the Association of Science-Technology Centers (ASTC) based in Washington, DC and supported by the international Biogen Foundation. In 2016, Scitech Discovery Centre in Western Australia hosted the WBT and brought together students, teachers, researchers, industry personnel, and the general public to participate in a series of biotechnology-related events. The WBT included a biotechnology festival, Lab-in-a-Box (a series of specially designed biotech hands-on activities), science cafés and other discussion events, school and community outreach, and a youth ambassador programme. These components aimed to bring biotechnology to the public's attention and help them to understand its importance and social relevance. This case study is focused on the youth ambassador programme and draws from an evaluation of the WBT at Scitech (Rennie & Rennie, 2017), in which data were collected via observation and field notes; interviews with ambassadors, their parents, and mentors; ambassadors' diaries; and pre- and post-surveys. The final evaluation of the WBT provides an overview of the full programme (Boyette et al., 2018).

7.5.1 Context of the Programme

The WBT Ambassador programme aimed to increase the impact and visibility of biotechnology among a group of high school students, enabling them to experience biotechnology first hand, learn about its importance in the community, and use their learning to communicate about biotechnology with other students, their family, and wider audiences. To foster global collaboration in the programme, virtual exchange meetings were held with Ambassadors in other countries. At the end of the programme, one Ambassador was chosen to represent each country at a final world gathering in Japan in 2017.

7.5.2 Overview of the Program Activities

The Scitech WBT Manager invited academically talented students from different schools to become WBT Ambassadors. The group comprised three Year 10 students, three Year 11 students and one Year 12 student. A mentor was recruited for each Ambassador, including a pharmaceutical manager, a university science communicator, and five scientists working in biotechnology. Over a period of about five months, Ambassadors worked with their mentor outside of school to develop a project on a biotechnology topic of their choice, usually related to their mentor's occupation, and prepare a poster to synthesise their findings. The Ambassadors had five virtual exchanges with Ambassadors at science centres in Canada, Italy, and Thailand.

Part of the Ambassadors' role was to publicise the aspect of biotechnology they were researching, so to develop their communication skills, the Scitech WBT Manager led afternoon/evening sessions prior to the virtual exchanges (due to international time differences, these occurred late in the evening). These assisted Ambassadors to plan their project, design their poster, and learn how to communicate with others about their topic. Posters outlining the projects were prepared for display at the Perth Science Festival (part of National Science Week) in mid-August, where the Ambassadors interacted with visitors about their poster and demonstrated the WBT Lab-in-a-Box activities. The posters were later displayed at Scitech and the Ambassadors were present for the launch of Scitech's biotech-focused festival for schools and families, during which other WBT activities were featured. Ambassadors concluded their programme by making formal presentations about their projects at a public meeting at Scitech.

7.5.3 *Outcomes of the Biotech Ambassadors Programme*

The WBT Ambassadors programme gave seven students a unique learning opportunity to interact closely with a scientist, to pursue a particular topic in depth and learn to communicate about that topic. The Ambassadors were very able students and all produced outstanding posters and gave impressive, well-structured presentations about their project. However, each completed a different project and they had different learning journeys during their mentorships. Table 7.2 provides a flavour of their experiences by briefly describing the journeys of Hayley and Kevin (pseudonyms are used for all Ambassadors).

Despite the Ambassadors' different journeys, the data indicated clear commonalities in the outcomes of the programme. The Ambassadors quickly became comfortable with each other and enjoyed the collaborative learning that occurred during

Table 7.2 Overviews of Two Ambassadors' Journeys

Information	Hayley (Year 10)	Kevin (Year 11)
Why become an Ambassador?	Wanted a challenge for herself outside of school.	He was interested and his parents were very keen that he participate.
Project topic	Drugs used for multiple sclerosis	Misconceptions about genetic modification.
Mentor and mentoring	Pharmaceutical manager; some face-to-face meetings, also email. Preferred face-to-face.	A mature PhD student; had face-to-face weekly meetings.
Approach to topic	Mentor used brochures to explain a difficult topic so Hayley could then "translate" more difficult articles. Hayley worked fairly independently, with mentor offering advice when needed. Mentor was impressed by Hayley's explanations on her poster.	Discussion with Mentor about trying to make GM relevant to the everyday world, and exploring pros and cons. Used a survey to find out about people's understanding/ misunderstanding of GM, and was surprised to find that people had firm, often opposing, views.
Particular outcomes	Enjoyed sharing her new knowledge with others. Big increase in knowledge and confidence. Doing the research helped Hayley understand the importance of communication. Found that she learned well by talking with others.	Enjoyed doing poster, but not presentation to large audience. Enjoyed talking to small groups at the Science Festival. Big increase in knowledge and confidence, although still shy in front of a large group. Became positive about importance of communicating science and technology, and more aware of the risks involved.
Final comment from diary	"I have gained so much during the program. I learnt so much about MS and gained skills to talk to in front of people as well as communicating science to the general public."	"A great learning experience as I was able to speak with someone who is extremely knowledgeable on the subject of genetic modification and he was able to help me further my understanding of the topic."

the sessions held at Scitech prior to the virtual exchanges. They enjoyed the experience of talking to other Ambassadors during these exchanges and finding out what students in other countries were doing. Two Ambassadors were delighted to have visited their mentor's laboratory and gain some experience of what "science was really like".

Ambassadors found talking about their project with members of the public very illuminating and learned some of the basics of science communication. Anna, whose project was about epigenetic inheritance, pointed out that "my use of anecdotes and analogies did help a lot with explaining my topic", and Sheela, who studied photoreceptor cone cells and vision, wrote in her diary that she learnt "a lot about how it is easier to launch into a more technical explanation once the general idea of it has interested the audience".

All Ambassadors enjoyed the leadership role they took during their participation in the Perth Science Festival and were pleased with their final presentation, despite being nervous at the start. By preparing a poster and a presentation, two very different kinds of communication skills were learned. The Ambassadors had a specialised topic they understood in some depth and their presentations revealed how they had created imaginative and novel ways to tailor that knowledge to suit the audience to whom they were speaking. The evaluation found that this gave them considerable personal confidence and a very positive attitude towards biotechnology and its importance in today's world. As Hayley noted in her diary after her day at the Perth Festival, "It was very interesting to note how many parents wanted to know how they can get their children into the program. I guess what we are doing is very impressive."

7.6 Discussion

The case studies in this chapter provided opportunities for students to develop their literacy in science and technology as described in Table 7.1 (and, for the first two case studies, this has been demonstrated elsewhere, Rennie, 2006). Each case study illustrates the commonality between STEM, creativity and critical thinking. STEM learning occurred in the context of genuine community issues that could be described as socio-scientific, a term that privileges science, but these issues required the integration of other subject areas as the need arose. It is important to note that this facilitates a balance between disciplinary and integrated knowledge to be achieved. These experiences provided opportunities to learn and practice the skills of creativity and critical thinking in a cross-curricular way and, in terms of the Four Cs (NEA, n.d.), opportunities to develop skills in communication and collaboration.

Illustrations of the OECD's four interrelated dimensions for critical and creative thinking – inquiring, imagining, doing, reflecting – can be found in all case studies. Inquiring was the first step students took in getting to grips with their issue. The students exploring the disposal of intractable waste drew on a range of resources and selectively organised their information on wall charts as they endeavoured to understand the issue. Students shared the workload collaboratively as they brainstormed ideas about what to do next and how to test their ideas, such as inspecting the transport safety features of the road. Expert groups studied particular aspects, brought the information back to the whole class, and then, having synthesised and reflected on their findings, the students decided to design, make, and distribute a brochure as an effective way to communicate their understandings to their community.

A similar process occurred in the second school-based project. Students at the Wildlife Centre began with inquiry, learning about and looking at real snakes, and then surveying community attitudes. Their findings endorsed the need for more community understanding and tolerance of tiger snakes and a variety of means for communication – posters, dioramas, short illustrative dramas – were planned, created, and presented at the final community night. The WBT Ambassadors worked independently with a mentor to choose and explore their topic, organise their information, synthesise and analyse their findings, decide what were the key issues, and evaluate the best way to communicate them in a poster and presentation to the different audiences at a festival and a formal evening event.

Creativity, particularly in generating ideas, finding ways to organise and present information, and critical thinking in terms of analysing information, reflecting on findings, assessing progress, and deciding what information should be used and how it would be presented, were evident in each case study. Coincidentally, posters were an outcome of each project, but the creation of these, and the other means of communicating their findings, was the culmination of a collaborative process. In schools, this was group work, but even though the Ambassadors' projects were independent, they collaborated not only with their mentor and the Scitech WBT Manager, but exchanged experiences and ideas with the other local Ambassadors prior to the virtual exchanges, where they could share ideas and stories about their experiences.

As might be expected, it was noticeable that the OECD's four dimensions for critical and creative thinking are not sequential. Certainly, students started with inquiry, finding information, but from then on they moved back and forth between organising and analysing information, generating ideas, testing them by pursuing new information, reflecting on what they were doing, and evaluating progress. It is significant that there was a recognisable end point in each case study because that created a tangible focus. Students had a task; a problem to solve, and they knew when it had been achieved. This is a characteristic of most successful school-community projects (Rennie, 2006).

There is a caveat to this rosy story. Implementing a school-community programme requires a great deal of time and effort by teachers to arrange excursions, coordinate incursions from community members, and negotiate the curriculum within the available time. This requires motivation and considerable skill by teachers (Rennie, 2011). For example, teachers in the Living with Tiger Snakes project found they had to suspend some planned curriculum activities in other areas to devote more time to preparing presentations and exhibits for the community night. This required readjusting their timetable and juggling curricular priorities, and to justify this it was essential that the project became an integral part of the school curriculum, and not a time-consuming addition to it. Although the Ambassadors' schools were not involved in their projects, the students had to learn to manage their time with the demands of their school work, and this occasionally required some understanding from their teachers. Leadership from the Scitech WBT Manager was an important component of their success in achieving their goal, as was the commitment and effort of their mentors, who gave their time freely to organise meetings and assist the Ambassadors during the mentoring process.

7.7 Conclusion

The case studies demonstrated that taking students outside the classroom and providing them with learning activities that require interaction with local community issues can benefit their STEM learning and development of creativity and critical thinking in at least three ways. First, students can test the disciplinary knowledge they have learned in a real-world, authentic context. Experiencing the application of disciplinary knowledge in life outside of school demonstrates that the real world is interdisciplinary and complex, with many variables intertwined. This helps students to appreciate that good understanding requires an appropriate balance between disciplinary and interdisciplinary knowledge in order to understand and solve problems in the outside world.

Second, by connecting with issues outside of the classroom, students experience a sense of the "bigger picture". This gives context to their learning and enables them to realise that what they have learned in a local context can also have meaning in a more global context beyond their classroom. Simply learning about intractable waste in their classroom would have had little meaning to the students in the first case study. Exploring the issue in the community context gave it much more meaning, enabling students to see the social, environmental, and political ramifications. Students in the second case study learned that tiger snakes are not merely creatures to be feared and possibly killed if found in their backyard; they are creatures who have an important role in the ecological well-bearing of the wetland area. This can develop the connections between knowledge of tiger snakes in the local wetland and the concepts of ecological balance in wider, more global contexts. The WBT Ambassadors were able to explore how the laboratory-generated biotechnological knowledge in their particular project has implications for the benefit and health of the wider community, but there are also risks involved.

Third, when students work on issues that are important to their local community they have opportunities to develop their senses of social and ecojustice, as they face matters relating to social and environmental values and diversity. This was clear in both school-community projects involving the disposal of intractable waste and living with tiger snakes, and also in the biotechnology projects where ethical decisions were often at stake. Students were involved with real and recognised community issues that provided opportunities for STEM learning in context. Besides gaining relevant cognitive knowledge and skills in creativity and critical thinking, they explored values relating to environmental conservation, sustainable development, ethical behaviour, and responsibility.

These case studies of students' learning from out-of-school activities have demonstrated that in making school-community links the outcome for students was powerful knowledge. Not only did students benefit from increasing their knowledge, particularly in science and technology, in an integrated context, they developed and practiced the skills of creativity and critical thinking, and began to develop a sense of ecological and social justice. As Rennie et al. (2019) concluded from their exploration of adult learning in science and technology, these are exactly the kinds of learning activities and outcomes that build confidence and create self-directed learners.

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