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Teaching science concepts through story: Scientific literacy is more about the journey than the destination

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ABSTRACT

Scientific literacy and critical thinking are crucial skills needed by students to navigate the science-based issues of the twenty-first century. This article focuses on the potential of visual-narrative storytelling as a multimodal teaching and learning framework to integrate multiple levels of meaning. In an already-packed curriculum, we propose our science-inspired graphic novels and picturebooks offer a model for teachers from different disciplines (e.g. English, history and science) to effectively collaborate, providing a richer engagement with each learning area.

Introduction

We live in an era dominated by science, technology and spin. A growing number of environmental, social and political issues are increasingly linked to science (e.g., climate change, artificial intelligence and genetic engineering). At the same time, these issues are communicated through information-saturated media, heavily influenced by propaganda, hysteria and bias (Alexander et al., 2008; Dahlstrom, 2014).

The Australian Curriculum (2020) states that 'responding to the challenges of the twenty-first century – with its complex environmental, social and economic pressures – requires young people to be creative, innovative, enterprising and adaptable, with the motivation, confidence and skills to use critical and creative thinking purposefully'. Yacoubian (2018) argues that citizens must be scientifically literate in order to best contribute to democratic decision-making, adding that 'science curricula need to encourage the development of learning outcomes and objectives that facilitate deliberative discussion and underscore critical thinking, placing the focus on the thinking process more than on the outcome' (p. 321). Doyle (2019) agrees, pointing to the recent rebranding of STEM (Science, Technology, Engineering and Mathematics) to STEAM, to argue the arts bring 'a language of interpretation (creative thought and critical thinking) and expression' (p. 43).

Integrating the language of arts and humanities into the teaching and learning of science places the emphasis more on the journey (literacy in science) than the destination (scientific literacy).

However, in spite of the growing importance of science and its technological offspring, many students struggle to engage and many simply aren't interested. One barrier is the challenge of comprehending linguistically complex text, especially for newly-arrived English learners (Tretter et al., 2019) and students from low socio-economic status backgrounds (Rojas, 2019). The decline in student motivation and attitudes towards science have been well documented (Osborne et al., 2003; Potvin & Hasni, 2014), particularly as students transition through secondary school. Fang (2006) observes that middle years readers are often alienated from science by the expectation that they suddenly move from learning concrete concepts to abstract ideas, while also having to navigate specialised technical language. Their recommendation is that educators (judiciously) 'replace science textbooks with educational novels that present scientific information in a storybook format' (p. 515).

Teaching science through story

In the mid-20th century, Lévi-Strauss (1966) argued that humans have effectively used stories for a very long time to pass on cultural knowledge to succeeding generations. Since this time, we have learned that narrative structures represent the default mode of human thought and that in the context of teaching science literacy, narratives can 'generate more attention and engagement than traditional logical-scientific communication' (Dahlstrom, 2014, p. 13614). Science-inspired stories, Klassen (2010) adds, should 'not only produce learning, but they also heighten the motivation to learn and stimulate the raising of pertinent questions that results in further investigations by the students' (p. 314).

Picturebooks, graphic novels and comics are ideal formats for creating science-inspired stories. All are capable of integrating a wide range of visual meaning-making modalities together with text-based language. This visual element is particularly important in this context, given the common use of diagrams, graphs, symbols, etc. in science to convey important meanings (Avraamidou & Osborne, 2009), and that 'images can make science content more accessible, engaging and memorable to youth' (Spiegel et al., 2013, p. 3). Graphic novels and comics also use a rich visual vocabulary of marks and symbols to incorporate and translate invisible movements, emotions and scales, as well as intertextual elements (Czerwiec et al., 2015). In our increasingly screen-based world, graphic novels and comics offer a middle ground. These part-text, part-visual formats can engage a broad spectrum of readers, particularly the reluctant kind, as well as those 'most comfortable with visual media, such as video games, YouTube and computer graphics' (Crocetti, 2017).

Moreover, the combination of visual and text can be greater than the sum of their parts. Wolfenbarger and Sipe (2007) emphasise their preference for the term *picturebook* to recognise how 'the union of text and art … results in something beyond what each form separately contributes' (p. 273), with each mode enhancing the comprehension of meaning of the other, expanding the potential for understanding and engagement. Through their integration of words and pictures, graphic novels and comics can also concretise abstract scientific concepts, helping to 'organize complex information within a narrative structure, and invite readers to relate emotionally to characters and situations through personification of inanimate things' (Matuk et al., 2019, p. 8). It can also be argued that picturebooks, graphic novels and comics offer a less intimidating and richer context to introduce new technical vocabulary, particularly for struggling learners.

Introducing scale free network: Art-science collective

In 2008, we (visual artist Briony Barr and microbial ecologist Gregory Crocetti) began teaching interdisciplinary workshops in schools, galleries and science institutions, combining microscopes and drawing with elements of history and mathematics to spark curiosity about 'invisible' worlds, beyond human vision. Inspired by the early 19th century discipline of natural philosophy, where the divide between disciplines was far less rigid than it is today, Scale Free Network projects embrace transdisciplinarity as a pedagogical approach and regularly involve collaboration with other arts and science practitioners, as well as educators, designers and students.

At the core of our philosophy is the desire to address two key issues relating to the microscopic world:

1. Human-scale-centrism: humans tend to only pay attention to things that they can see, when in reality, less than 1% of all biodiversity on planet Earth is 'visible' to the naked human eye.
2. Fear of microbes (e.g. bacteria, viruses, nematodes etc.): our collective misunderstanding of, and hostility towards, microbes means we are missing important lessons that are much bigger than just communicating science. In the context of the COVID-19 global pandemic, we think this understanding is more urgent than ever.

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Volume 28
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An ecology of literacies

In 2013, we began making picturebooks, using narrative to portray hidden, abstract relationships between microscopic characters and larger creatures (particularly animals). We were keen to include a visual component as a core element in our storytelling framework: partly to help tell the story and partly to help incorporate scientific content. We also had a strong sense that we wanted to target upper primary school learners – ideally before most children begin to lose (or hide) their innate curiosity in nature. And so, the idea to make a series of illustrated, microbiology-inspired narrative non-fiction picture-books was hatched!

Our goal was to create a different kind of information book: one that looked beautiful, presented accurate science, introduce new scientific vocabulary and could engage a wide range of learners through the power of a good story. We also wanted to create an alternative textbook able to be incorporated in various ways in different kinds of classrooms and to appeal to different kinds of learners – including those who self-identify as 'more interested in science' or those 'more into art'.

From the beginning, we adopted a transdisciplinary approach and assembled a team of visual arts, literature and scientific experts to develop a storytelling methodology: collaborating with writer Ailsa Wild; visual ecologist Aviva Reed; and microbiologist Professor Linda Blackall. Writers and artists bring a range of multimodal devices and languages for expressing and representing scientific concepts (Doyle, 2019), while scientists bring deep knowledge of complex and abstract phenomena – particularly those we cannot see – along with metaphors and analogies to help explain them (Dahlstrom & Ritland, 2012). By bringing these different ways of knowing together, we hoped to facilitate a rigorous dialogue between each kind of practitioner and, through this process, to create an authentic, multimodal ecology of literacies (a phrase inspired by 'Ecology of Knowledges' in de Sousa Santos, 2008).

The *Small Friends Books* series (CSIRO Publishing, 2020) is now co-published in Australia by Scale Free Network and CSIRO Publishing and will soon be released in Korea and China. Each book contains approximately 30 pages of illustrated story and 14 pages of scientific explanations (Table 1). And while the series is officially marketed to target upper primary school audiences, it is used and read by other age groups, including adults.

Table 1. Titles in the *Small Friends Books* picturebook series.

Zobi and the Zoox: A story of coral bleaching	2015/2018
The Squid, the Vibrio & the moon	2014/2019
Nema and the Xenos: A story of soil cycles	2019
The forest in the tree: How fungi shape the Earth	2020

In 2016, we co-created and published *The invisible war: A tale on two scales* (Barr et al., 2016), a microbiology/history-themed graphic novel, in collaboration with writer Ailsa Wild, comic artist Ben Hutchings and scientist Dr Jeremy Barr. The story describes the parallel stories of Australian Nurse Annie Barnaby working behind the trenches of the Western Front in the First World War, alongside the life-or-death battle between microscopic protagonists in her gut. This title comprises 64 pages of comic story and 24 pages of scientific and historic explanations and was designed to target middle school students (particularly Years 7–9). It has won multiple design, educational and literary awards and has since been published in North America, Korea, the Middle East. Susan Merrill Squier (in de Leeuw et al., 2018) declares that *The Invisible War* 'bravely moves beyond the silos of academic, artistic, and scientific disciplinarity, inviting a broad range of readers and users' (p. 297).

The end of a story provides an opportunity for students to reflect on new information in a more engaging way compared to expository modes of learning (Klassen, 2010). Thus, with each of our books,

we provide an information-rich reference section to exploit learner curiosity and motivation evoked by the story. In this section, we embed a range of additional modalities to further contextualise and explain the scientific (and historic) content embedded into the narrative. These include photographs, micrographs, additional diagrams, Linnaean classification tables, scientific illustrations, newspaper clippings, timelines and flowcharts, explained with accessible, expository text.

Our books are accompanied by Teacher Notes containing individual, group and teacher-led activities and discussions. In addition to exploring several fundamental middle year science concepts, such as the structure of the cell, classification, ecosystems and evolution, our books and teaching resources also provide teachers with entry-points into other subject areas, particularly English, history and the arts.

Multimodalities in our books

The following section provides some examples of the modalities and literacy devices within our books and how we employ them to engage middle school readers.

Character voices and perspectives

Before creating our first book, we decided to avoid using humans to narrate the microscopic elements to our stories, such as in the *Magic School Bus* book/TV series (Scholastic, 2020) where American school children and their teacher board a magical school bus to travel to unusual times and locations, including shrinking down to witness microscopic phenomena. The decision not to integrate human subjectivity in our stories was made in line with our philosophy about decentring the human: the default lens through which to encounter the world. Instead, our narrators are the microbes themselves (e.g. bacteria, viruses, fungi) and the stories are told from their perspectives, described using either first person or third person point of view (Figure 1). Each story draws on different archetypal characters and situations (e.g. the 'hero's journey' or a 'coming of age' story/bildungsroman) to help readers relate the experiences and agency of microscopic characters (their decisions, challenges and failures) to a more familiar, human-scale perspective. These choices are part of our broader goal to spark the reader's 'ecological imagination': the ability to think beyond a human-scale view of the world. By encountering these microbial perspectives through our stories, students are invited to explore their own ethical point of view and behaviours in relation to non-human beings, similar to more conventional considerations of animal rights.

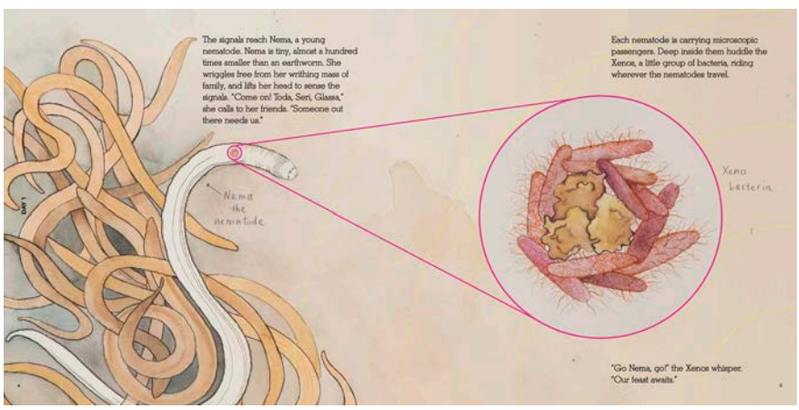

Figure 1. Nematode and bacteria begin their journey into the soil in *Nema and the Xenos*.

In contrast to all our picturebooks which never include any human presence, our graphic novel moves between experiences on both the micro and macro scale, juxtaposing the perspectives of bacteria and viruses with human points of view.

The invisible war is set on the Western Front of World War 1, with nurse Annie Barnaby chosen as the main human protagonist to avoid telling yet another World War 1 story from the perspective of a male soldier (Figure 2). This context connects with important curriculum elements, particularly the rights and roles of women in the early twentieth century and during World War 1.

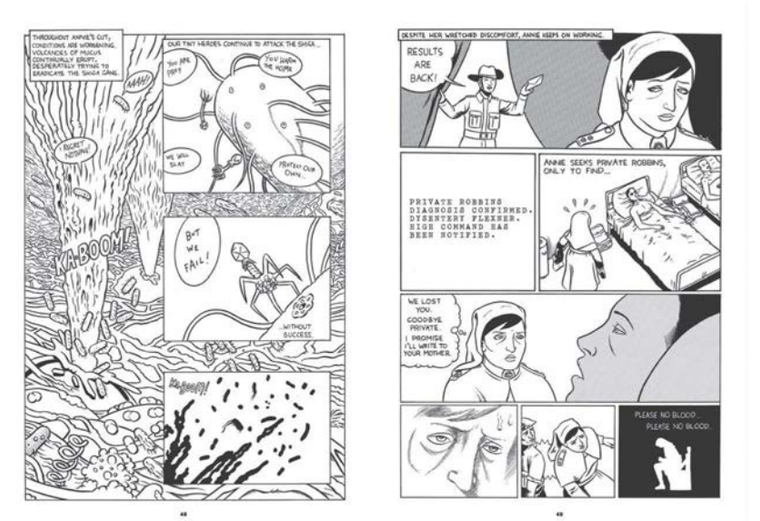

Figure 2. Parallel perspectives: microbial (bacteria/viruses) and human (nurse Annie Barnaby) in *The invisible war*

Chemical conversations

One of the most central aspects to driving narratives is the dialogue between characters. In the non-human world, microbes, plants and other creatures mostly communicate through chemistry, a molecular code that enables 'speaking' and 'listening' across both tiny and vast distances. In our stories, we use dialogue as an analogy for these chemical conversations (Figure 3), but also depict the chemicals as part of the illustration in the form of hand-drawn ball-and-stick molecules (explained in further detail in the science section). The use of this analogy in our stories invites opportunities for students to analyse how scientific information is represented in the story and the ways figurative language can be used to construct meaning in different contexts.

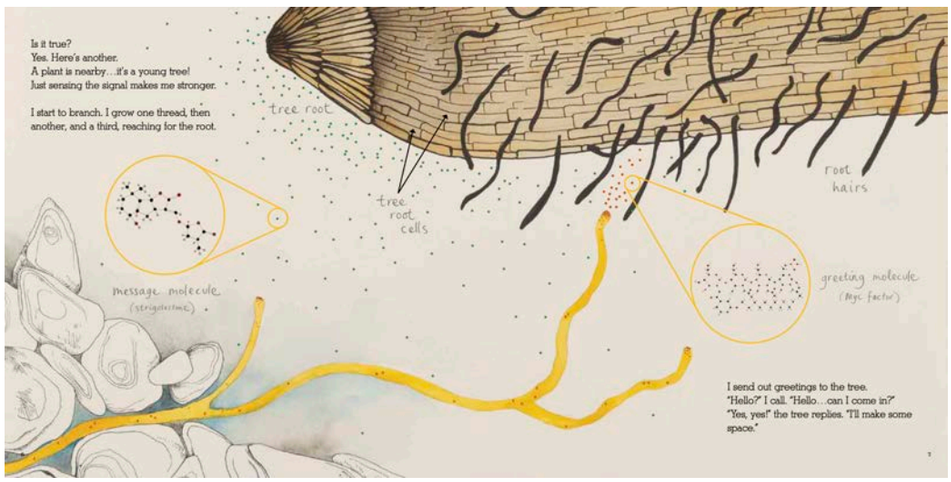

Figure 3. Dialogue between fungus and tree in *The forest in the tree*

Using visual language to make meaning

Illustrations are a powerful way to represent phenomena we cannot directly see and concepts we cannot imagine. Wolfenbarger and Sipe (2007) suggest the art in picturebooks can convey 'size comparisons, textures and habitats' (p. 276) unfamiliar to readers. Moreover, both picturebooks and graphic novels can introduce new scientific phenomena and concepts without needing to include intimidating or overwhelming quantities and units. Instead, visual elements can be used to communicate complex and abstract ideas to the reader. In our books, we regularly feature 'zoom' (magnification) circles, as well as photographs, maps, diagrams, arrows and visual sound effects.

In the picturebook *Zobi and the Zoox* (Wild et al., 2018), readers experience the phenomenon of coral bleaching – from the huge scale of the Great Barrier Reef, down to the tiny scale of the microbes living within a single coral polyp – without encountering specific values (e.g. size, temperature, time) in the story. To help represent the complex size relationships, we digitally integrate hand-drawn pencil labels and 'zoom' circles with watercolour illustrations (Figure 4). These visual devices help to communicate parallel action across multiple scales of distance and time.

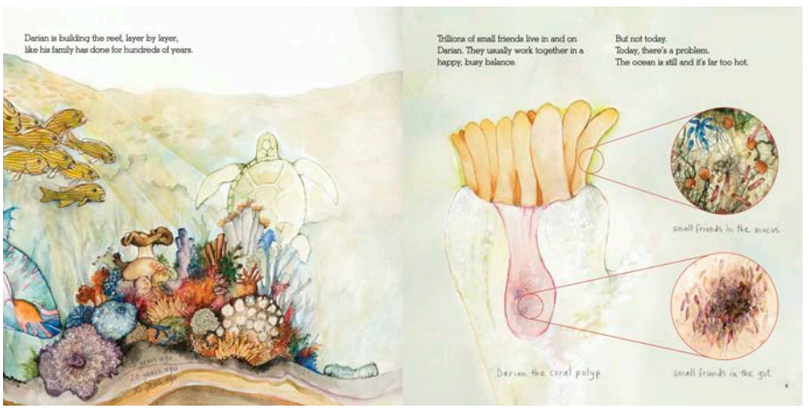

Figure 4. Introducing Darian the coral polyp at different physical scales, in *Zobi and the Zoox*.

A convention of graphic novels and comics is the use of intertextual elements. *The Invisible War* draws on a wide range of historic and scientific references to help tell the story including poetry, maps, telegrams, medicinal labels, diagrams, flashbacks, dream sequences and song lyrics (Figure 5).

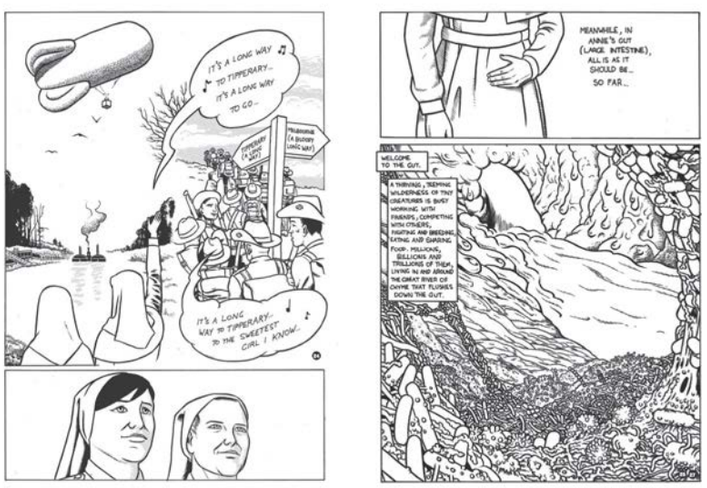

Figure 5. Use of song lyrics in *The invisible war*

We are all teachers of literacy, but some more than others

While 'we are all teachers of literacy' has been a catchcry in Australian education for decades, in practice, a whole-school approach to literacy has proven difficult to implement (Merga et al., 2020). Fang and Wei (2010) highlight that while secondary science teachers have the knowledge and responsibility to teach scientific literacy (conceptual understanding), they often lack the reading skills (discursive understanding) needed to help students learn effectively from science texts. In addition to greater emphasis on the development of literacy skills across all subject areas (Kirsten, 2019; Merga, 2020), we believe that more collaborative approaches amongst subject areas offer significant opportunities for the development of pedagogical practice.

When cross-curricular approaches happen, it can positively change the learning process (Roy, 2016). One such example was the collaboration between Year 10 science and English teachers to run the 'Making Science: Making News' project (Alexander et al., 2008), after which 'both science and English teachers on this project commented on how the collaboration opened up windows for them and that each was able to offer expertise and perspectives that the other was able to make use of' (p. 34).

English teachers have a fundamental role in helping students connect language across different texts but can also play a pivotal role in helping to develop literacy across different disciplines. In the context of our books, English teachers can help students consider how analogies, archetypes and character perspectives within the story text interact with different visual semiotics (e.g. symbols, sizes and colours) to make meaning.

English teachers can also play an important role in encouraging students to question science, supporting them to recognise how language can be manipulated to express particular ideas and influence people in scientific debates. As such, we believe that analysing, interpreting and explaining some of the new concepts encountered in our books can allow students to develop sophisticated critical thinking skills.

Conclusions

Questions about whether our schooling system is up to the challenges of the twenty-first century requires reflection on the way we currently approach teaching and learning. Schools are often too segregated and curricula too crowded for teachers to easily integrate learning across disciplines. Yet cross-curricular teaching can provide more context for student learning and create opportunities and time for deeper inquiries into each subject area, both within the classroom and beyond. School and curriculum leaders have an important role to play here in encouraging cross-disciplinary conversations and collaborations.

Our science-inspired graphic novel and picturebooks demonstrate an effective multimodal model for teaching scientific literacy. However, we believe that stories like ours can not only be used to communicate scientific concepts, phenomena and processes; they also serve as a transdisciplinary resource that teachers can use to collaborate across learning areas and literacies, expanding the potential for students to journey deeper into their thinking as they reflect on the meanings and questions raised through the story. We believe this approach will enhance much-needed critical thinking skills and help enable growing minds to better navigate the science and spin that continue to shape our world.

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Briony Barr is a visual artist whose practice incorporates individual and collaborative drawing, interdisciplinary collaboration, storytelling, installation design and workshop facilitation. Underscoring much of her practice is an interest in using drawing to represent a process of change, duration and emergence. Briony holds a BA, BFA and MFA and is an honorary fellow of the University of Melbourne's School of Physics.
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