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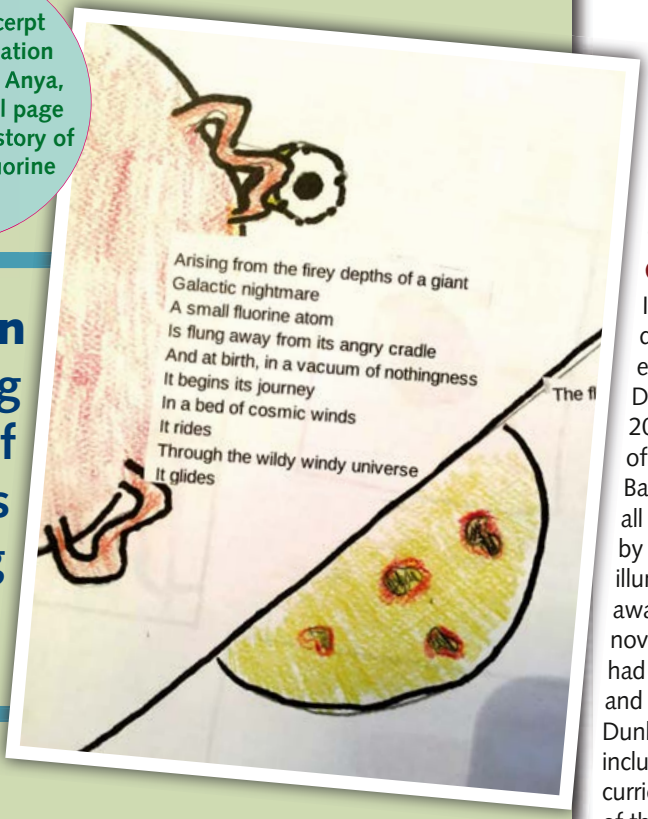


Figure 1 Excerpt from 'The Creation of Fluorine' by Anya, a graphic novel page detailing the history of an atom of fluorine

Eric Fishman explores telling the stories of the elements by creating graphic novels

Inviting narrative back into the science classroom

'*But where do they all come from?*' a student invariably asks when I teach about the elements. The first few times this happened, I gave a simple explanation about the different sources of various elements on Earth: '*Well, for example, there's carbon from rocks in the ground and carbon dioxide in the atmosphere.*' In the way that children do, though, my fourth grade (age 9–10) students in Boston, Massachusetts, pushed me further and further: '*But how did it get into the rocks?, How did it get to Earth in the first place?*' Eventually, I realised I didn't know the answer either, and so I set out to investigate. The research I did would lead me in a wholly unanticipated direction: telling the stories of the elements through graphic novels.

Science and storytelling

Science and storytelling have an uneasy relationship. The scientific community frequently disdains stories, seeing them as polluting the purity of objective communication of data. In the peer-review process, for example, scientists who tell stories with their data are seen as '*embellish[ing] and conceal[ing] information to evoke a response in their audience*,' far from the ideal of the bias-free scientist (Katz, 2013). More broadly, Western culture as a whole has '*fetishized objective expertise for most of the past century*', viewing this objective expertise as a major currency of power in public discourse (Jones and Crow, 2017).

I, too, had a longstanding discomfort with narrative in the science classroom. For example, when I taught secondary science, I resisted using analogies to explain atomic bonding. It felt like a betrayal of reality to say that '*the bully chlorine*' was '*stealing an electron*' from potassium when they bond to form potassium chloride. In my attempts to cultivate young scientists who are dispassionate observers of scientific phenomena, personification felt counterproductive. I used stories and characters occasionally because I saw that they helped some students engage and remember the content, but I felt uneasy with the inaccuracy involved. I retained this anxiety with scientific stories as I shifted to teaching in a fourth grade classroom at an independent school for high capacity and twice exceptional students (high capacity students with special needs). Teaching the elements with graphic novels, however, shifted my thinking about stories.

Graphic novels

I was ruminating on my student's question about the origin of the elements as I came across James Lu Dunbar's *The Universe Verse* (Dunbar, 2013). This graphic novel tells the story of the universe, from before the Big Bang through the scientific revolution, all in rhyming couplets. I was drawn in by the joyous ease with which Dunbar illuminated complex topics. I was well aware of the resurgence of the graphic novel as a genre – many of my students had become obsessed with the *Amulet* and *Bone* graphic novel series – and Dunbar made me consider how to include graphic novels in my science curriculum. The question about the origin of the elements presented an intriguing opportunity.

Our project on the elements

After some research, I discovered Jennifer Johnson's 'Origin of the Solar System Elements' periodic table (Johnson, 2017). Johnson, an astronomer at Ohio State University, got bored during a conference and began to shade the periodic table by the elements' origins: big bang fusion, exploding massive stars, cosmic ray fission, and a handful of others. I decided to have my students choose one element each, focusing on the elements found in the human body. They would tell the story of one atom of the element, from its moment of origin to its role in the human body.

The more I thought about the project, the more I felt that a story was the perfect way to bridge the massive gaps of time and space involved in tracing an atom's history. Particularly for younger students, whose abstract reasoning and time horizons are already limited, stories give access to scales that might otherwise remain incomprehensible. Indeed, research suggests that, since stories are simple to absorb into the memory as sequences of events, they can help students to understand complex chains of causality (Rowcliffe, 2004).

This article focuses on the project I taught my students, using the elements. However, I want to emphasise that graphic novels, and storytelling more

Key words: Graphic novels ■ Elements ■ Storytelling

broadly, could be used in any curriculum that requires students to visualise movement over time and space, such as exploring the flow of matter in an ecosystem, modelling geological histories or analysing chemical reactions. The overarching goal of this project is for students to tell a story of chemical 'migration' using research-based graphic novels. This goal, as well as the structure of the unit, could be utilised in a variety of curricular niches.

Researching and structuring the stories

In rolling out the project to students, I told an element story of my own, tracing the history of an atom of fluorine 'backwards', from its structural role in a tooth, back through its presence in a tea plant, the soil, and the Earth's crust, its long journey on interstellar winds, and finally its origin in a supernova.

After choosing their element from a list of elements in the human body, the students did their own research. Using a variety of differentiated printed and online sources, they took notes in order to 'storyboard' four steps of their chosen element's journey: its origin, how it got to Earth, how it got into food, and what it does in the human body. This process was challenging for many of the students, as the topics addressed were complex and varied – astrophysics, geology, ecology, biology. I could imagine an entire semester-long unit built around this project, although we spent only a few weeks on it. Carefully curated sources, matched to students' background knowledge and reading levels, were essential.

After their research, I gave the students two options of how to write the story: prose or poetry. I adapted a rubric the students had used in previous writing units, in order to outline the expectations around content, literary techniques, and organisation (Box 1). I asked the class to utilise poetic devices we had been studying in order to match their *form* (the way they told their story) to the *content* of the story, and connected this idea to how structure and function connect in scientific systems. The rubric was useful to give students feedback during the writing process as well as to evaluate their final drafts. We proceeded through the same structures of drafting, self-revision, peer-revision and teacher conferences that we had used in previous writing units.I provided differentiated sources for students with reading disabilities, including adapted online articles and books at a variety of reading levels. I implemented additional scaffolding during the writing process for students with writing disabilities, such as scribing (student dictates for a teacher, who records their thoughts), sentence starters (possible starting 'frames' for sentences) and other executive functioning tools. The goal was for all students to successfully complete the foundation of the assignment: to tell the atom's story using research. The artistic component of the assignment was a boon for students who often struggled with writing assignments. I would even consider reversing the order of writing and art for some students. For those with significant writing disabilities, telling their atom's story through pictures first could be an effective scaffold towards the writing portion of the assignment.

I was impressed by the level of engagement across my classroom. The project was flexible enough to meet students at different writing levels, and students produced some of their most evocative writing of the year. One of my students was so proud of his work that he told me he was now considering becoming a poet. Another student, who had been acutely self-conscious about her previous writing assignments, later decided to submit her story to the school literary journal.

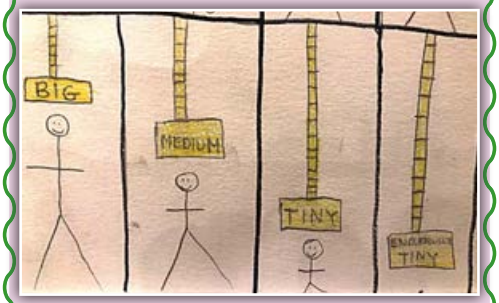
As they were finishing up their writing, the students began work on their illustrations. The art teacher came in and helped the students brainstorm different ways to format a graphic novel page. We looked at exemplars from different graphic novels, including *The Universe Verse*. Students considered how their artistic decisions would affect the experience of the reader. What ideas were most important to convey, and how could they depict those ideas visually? Again, how could the *form* of their artwork match the *content* of the story?

The students sketched and revised

Box 1 A rubric for formative and summative assessment of the writing portion of the graphic novel project

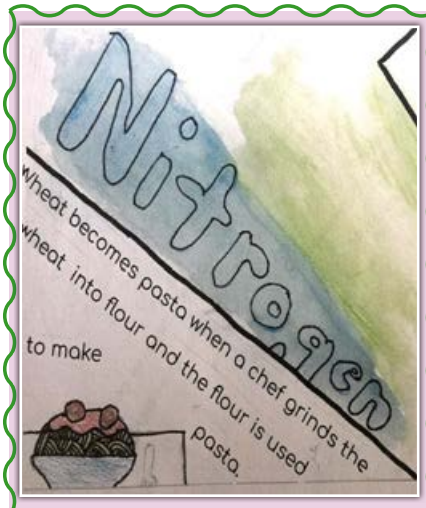
What works well?	Properties of a successful element story	What could be improved?
	Content • Is the information well researched and correct? • Do you explain all four steps of the atom's journey (origin, how it got to Earth, how it got into your food, what it does in the body)? • Do you meet the minimum length requirements: at least 16 lines for poetry or 12 sentences for prose?	
	Literary techniques • Does your story use at least 3 similes or metaphors? • Does your story use at least 3 examples of sound techniques (alliteration, consonance, assonance)? • Does the *form* of the story match the content? In other words, does the *way* the story is told match what is happening in the story?	
	Clarity and organisation • Is the story easy to understand? • Does it flow well? • Does it tell the story chronologically (forward in time) in a way that makes sense? • Could a reader in our classroom understand the science from reading this story?	

Figure 2 Excerpts from 'Zinc's Journey', by Alex, a graphic novel page detailing the history of an atom of zinc



Zinc comes from stars
That are not as red as Mars
It exploded with other elements (POW!)
Then it started its journey (WOW!)
Where did it go on that journey?
It came to Earth, you turkey!
It settled in the Earth's core
The birth of zinc and more …
[the zinc makes its way into an oyster and is eaten]
As the zinc arrived at the very end
It started working on the body – to help it mend
The body that the zinc aided to grow
Won in the big, dramatic, final blow
Cause the other big people who didn't get zinc
I'm sorry to say they began to shrink
And shrink
And shrink
And shrink
And shrink

Figure 3 Excerpts from 'The Creation of Nitrogen', by Vera, a graphic novel page detailing the history of an atom of nitrogen



Then nitrogen got into the soil. Wheat started to sprout. When the silent wheat seed goes in the soil, the outstretched roots of the seed take in the nitrogen …

their designs before starting on their final illustrations with coloured pencils and watercolours. Some of the students who had struggled the most with the writing portion of this project flourished when presented with this artistic opportunity. Several students took their projects home to devote additional time to them, even though this was not required.

Presenting the graphic novels

After students finished their final drafts of the writing and art, they experimented with the layout of their final page, choosing how to place their text for maximum effect. We wrote a class introduction for our stories, and then I copied the students' work and bound them together into oversized books. The students invited their parents to a publishing party to present their work, and then hung up their original pages on the wall outside the classroom (Figures 1–3). Throughout the month that they were posted outside, I saw many students, both older and younger, stopping by during recess to read the pages and talk with my students about their stories. They were an excellent conversation starter.

In order to tell these stories, the students needed to develop a profound understanding of the scientific content. Narrative requires clarity. If a student is confused, this confusion will quickly manifest itself in a nonsensical story. Literary techniques such as metaphors also necessitate strong scientific understanding. If I am trying to choose a metaphor to help my reader visualise a supernova, for example, I must first have a firm grasp of the conditions that are actually present in these massive explosions. In these ways, stories can act as a resource for formative and summative assessment as well as for instruction.

In addition, the stories' effectiveness in sparking scientific dialogue in the school community is indicative of the importance of narrative in communicating scientific information. Scientists are beginning to realise how their fear of narrative has been detrimental to their ability to help educate the public about their findings (Dahlstrom, 2014). The scientific community's single-minded emphasis on logical-scientific communication is one of the factors behind widespread misconceptions in fields such as climate change, sustainable energy, and vaccines (Jones and Crow, 2017). If scientists do not tell cogent stories about their findings, the media will rush in to fill the gap – often with disastrous results.

Storytelling and intellectual culture

If stories are an effective pedagogical resource, why do we see them relatively rarely in the science classroom? The insularity of subject areas is not a sufficient explanation: we must go deeper. In particular, the scientific community's avoidance of stories may be a by-product of the decontextualised nature of White, western intellectual culture. For millennia, people of all cultures told stories about the natural world. In many cultures, storytelling remains a powerful form of meaning-making and transfer of knowledge, inside and outside the classroom. For example, First Nations (Indigenous communities in Canada) teachers frequently use storytelling to great pedagogical effect (MacLean and Wason-Ellam, 2006: 7):

Storytelling … [is] a powerful and interactive instructional tool … Storytelling creat[es] a climate that is responsive to the individual needs of the classroom … [and develops] a dynamic of interactive shared learning and equality of learners.

In White intellectual culture, however, stories were banished by the 'rigour' of the scientific revolution. The scientific method leaves no room for stories. As the Sioux author, historian, and activist Vine Deloria Jr asserted (Deloria, 1997: 4):

During the European Middle Ages … once reason became independent, its only reference point was the human mind and in particular the middle-class, educated, European mind. … [Subsequent] generations of scientists [were encouraged] to treat an obviously living universe as if it were an inert object.

Stories are useful for conveying scientific content, but that is not the core of their importance for learning. Narrative is a fundamental aspect of human experience: stories are how we make sense of the world. By closing science off from the world of stories in the service of an 'objective' scientific mindset, we rob our students of the chance to invest personal meaning in the world around them.

We need scientists with humanity. Ethically complex emerging technologies, such as human gene editing, demand it. So does the crisis of global climate change – a crisis whose origins lie in apathy to the natural world. When we invite stories into the science classroom, we move toward a more just and sustainable future.

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