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Elements of Country: a First Nations-first approach to chemistry

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Abstract: Collectively, we have chosen to explore an Australian First Nations-first approach to understanding the chemical elements. We believe that engagement with cultural heritage, ongoing cultures, and the knowledges of *this place*—the lands on which we work, live, and study—will lead to new ways of understanding the elements and change the way we practice chemistry. The "First Nations first" phrase and approach comes from understanding the unique place that Aboriginal and Torres Strait Islander peoples have in the Australian context. In this paper we explore how a First Nations-first approach could take place in Sydney on Aboriginal lands. This approach is led by Aboriginal people, engages with culture, and is produced with local knowledge holders. So far, the work has entailed two years of meeting, conversing, and sharing space to determine appropriate ways of working together, interrogating the complexities of the ideas, and to refining our approach to the work. To appreciate the significant shift that a First Nations-first approach represents for chemistry, we consider the legacy of the Periodic Table. We share some reflections on how Indigenous knowledges can contribute to an expanded chemistry curriculum through the recognition of productive cultural tension.

Keywords: cultural heritage; First Nations-first; periodic table; translation.

1 Introduction

This paper was researched and written on lands that have never been ceded and never been sold. We acknowledge our debt to the many millennia of learning and knowledge exchange that has taken place on these lands which are now collectively called Australia. We offer our particular respect to the Elders past, present, and those to come of the Gadigal, Bidjigal, and Wangal who cared for Country long before the Camperdown campus of the University of Sydney and the surrounding suburbs were built, and where we work together.

Our team comprises both Aboriginal scholars from communities across New South Wales including the Gadi, Dharug, Wiradjuri, Ngarigu, Dunghutti and beyond, as well as non-Aboriginal scholars. The team brings together diverse expertise across chemistry, medicine, museum and cultural studies, anthropology, history, linguistics and visual arts.

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Our work has emerged from an interdisciplinary sharing and collaboration from Indigenous knowledges and languages, the sciences, history and the arts. We're interested in how a First Nations-first approach can influence the way chemistry is understood and taught in Australian universities. In order to pursue this, we are, and will continue to, work with Traditional Custodians of the lands of the Sydney region. This includes the 29 clans of the Eora nation. The Camperdown campus of the University of Sydney stands on the lands of the Gadi people, part of the Eora nation. The interconnected nature of peoples means our interests in exploring the elements includes not only the Gadigal but extends to include clan groups such as the Dharug to the west, the Kamay to the east, the Worimi to the north, and the Dhawaral to the south.

Essential background to this work is how chemical knowledge is currently understood and taught in Australian universities. The Periodic Table is emblematic of chemical knowledge, but it is not a fixed object. The many versions of the Table reflect changing understanding over time. The organisational methodology and spatial design of any particular example of the Table reflects its temporally contingency. There have been many translations of the elements of the Periodic Table including an increasing number in Indigenous languages beyond Australia (Andino-Enríquez et al., 2022; Natural Sciences and Engineering Research Council of Canada, n.d.; Stewart, 2010). While such work has the potential to strengthen intercultural understanding, it also carries with it deep questions about culture and cultural heritage. Which knowledge systems are prioritised in the process of translation? Which culture's understanding is facilitated by such translations? The focus on retaining the structure of the Table in many translations emphasises the priority given to the western approach to science. This reveals that the translation of the Periodic Table is often a mechanism for bringing the speakers of that language into a western cultural understanding. While a Periodic Table in translation provides a bridge between cultures, there is a missed opportunity when the knowledge and cultural understanding flows predominantly in one direction.

2 Terminology

This paper relies on nuanced application of certain terms.

"Aboriginal and Torres Strait Islander peoples" is the collective term for the Traditional Custodians of the lands that make up Australia. There are many distinct clans and cultures across the continent. We refer to clan groups by their preferred name where possible.

"First Nations-first" is a deliberate phrasing choice in this paper to emphasise the centrality of Aboriginal and Torres Strait Islander knowledge and perspectives. By drawing upon the repetition of "first", we seek to draw attention to this centrality as pivotal to the aims of our work together. "First Nations" is increasingly part of the Australian lexicon, but we recognise that "Aboriginal and Torres Strait Islander peoples" is more specific phrasing, which is why both can be found in this paper.

The capitalised form "Indigenous" is sometimes used when referring to the Traditional Custodians from more than one place or country. This usage is reflected in phrases such as "Indigenous knowledges". We offer this capitalisation is a mark of respect towards Indigenous people from and beyond Australia, but we acknowledge that this capitalisation may not reflect an accurate description of particular peoples or clans.[1]

The capitalisation of "Country" denotes the significance of the lands, water, and skies as not only a place on which Aboriginal and Torres Strait Islander peoples live their lives, but as a respected entity in her own right who is a repository of culture. The physicality of Country is directly tied to the ideas and stories that are drawn from Country. Memory and storytelling are essential ways of engaging with Country. Similarly, physical changes to the landscape matter deeply because of the consequences such changes have on how Country can be understood (Koch & Gillespie, 2022). It is possible to say that Country is the most central part of Aboriginal cultural heritage and still fail to capture the full importance of Country.[2]

Distinctions such as "Gadi" and "Gadigal" are significant. Gadi refers to place while Gadigal refers to the people of Gadi Country (Troy, 2019).

1 On some of the complexities that can be encountered with capitalisation of Indigenous, see: Eaton (2022).

2 On the interconnection of the land, sea, and sky with deeper ideas of spirituality, see: Grieves (2008).

The “Eora nation” is the broad designation commonly used by Aboriginal people in Sydney and given to the 29 clans that have ancestral ties to the lands of the Sydney region. The Eora nation is bounded by three river systems now known as the Hawkesbury, the Nepean, and the Georges River.

3 Cultural heritage in context

For at least 60,000 years, Aboriginal Peoples have lived and practiced culture on this continent, and are widely recognised as one of the world’s oldest continuing cultures (Clarkson et al., 2017). There is an intrinsic relationship between Country and culture as well as recognition that change is a consistent feature of both. This culture is not homogenous, but complex and dynamic; it has been affected by colonisation commencing with Cook pre-1788. Across the Australian continent, there are many Aboriginal and Torres Strait Islander peoples with their own histories, cultures, and knowledges. This includes scientific knowledge and there is increasing recognition that Aboriginal and Torres Strait Islander peoples were the first scientists (Hamacher et al., 2022; Tutt, 2021).

Cultural heritage is a distinct yet ambiguous concept. Cultural heritage thrives on a “process of categorising, ordering, listing and subsequently conserving and/or archiving” (Harrison, 2012, p. 6). The scope of cultural heritage has expanded over time, but what is overlooked is significant. Aboriginal and Torres Strait Islander people continue to fight for the preservation of sites with cultural heritage significance. This has involved significant campaigning by Aboriginal people for cultural connections to landscapes to be recognised by UNESCO and ICOMOS (Harrison, 2012, pp. 118–126; Koch & Gillespie, 2022). Cultural connection to landscapes reflects the place of Country in Aboriginal understanding. The practical implications of this deep relationship extend to any approach to the elements which are part of the lands, seas, and skies that falls under Aboriginal custodianship of Country.

This history holds implications when considering *translation*. There is potential for the scientific understanding of the elements inherent in Indigenous knowledge systems to be hidden and over-written by the knowledge systems inherent to the Periodic Table. This is a highly sensitive topic as Aboriginal and Torres Strait Islander peoples’ connection to culture/knowledge/language is often contested or ignored. For example, the Aṉangu people fought to have their cultural heritage recognised after Uluṟu was designated a “natural” World Heritage site rather than both a “natural and cultural” site in 1987 (Harrison, 2012, p. 122). As recently as 2020, the recognised cultural heritage of the Puutu Kunti Kurrama and Pinikura peoples was ignored by the mining company Rio Tinto when it destroyed the sacred Juukan Gorge site (Oliveri et al., 2022). Closer to Sydney, there is ongoing work to protect and offer culturally appropriate access to sites of significance in the Cubbitch Barta National Estate Area (Department of the Environment and Heritage, 2004, p. 18). This site holds importance for the Dhawaral and Dharug peoples and is recognised as a repository of art, archaeological deposits, and scarred trees. The significance of the area is substantial with over 530 archaeological sites known and another 509 potential sites documented (Department of Climate Change, Energy, the Environment and Water, n.d.). It is notable that much of the work to survey the Cubbitch Barta National Estate Area was undertaken because the site was proposed as the location for an airport (Department of Climate Change, Energy, the Environment and Water, n.d.). Across Australia, the necessity of fighting to protect Country and sites of significance is ongoing. Just as drastic alterations to Country can be viewed as “sacrilegious” (Koch & Gillespie, 2022), the act of simply translating the Periodic Table into an Aboriginal language may erase rather than celebrate and affirm culture.

A First Nations-first approach to understanding the elements begins with Aboriginal and Torres Strait Islander peoples and their ways of knowing, being, and doing (Martin & Mirraboopa, 2003). Such work is about more than translating the Periodic Table into language, there must also be a clear determination of how best to represent the elements and the relationships between them. For instance, a Table may not be the best mechanism to explore the understanding of the elements in the Aboriginal epistemologies of the Sydney region. Community-based research strategies will be important to find consensus on the best ways forward (Riley, 2021). An important step in this process will be to develop appropriate protocols with local knowledge holders for working collaboratively, respectfully, and with a care and commitment to the mutual benefits that the project can offer.

4 Approaching the elements

A consideration of the history of the Periodic Table is warranted as this is the dominant paradigm through which the elements are understood in chemistry. The names of the elements and the visual organisation of the relationships between them draws attention to how chemists have adapted representation in the face of changing understanding. This history underpins our proposal for the value in understanding of the elements from the paradigm of Aboriginal science.

4.1 On the names of the elements

The names of the elements in English are informed by history, but they are not systematic and excite controversy (Meija, 2021). There are various approaches to naming elements, but the results are not necessarily logical or pedagogically useful; sometimes the names are misleading or incorrect. IUPAC offers five naming options for new elements "keeping with tradition" including a mythological concept of character (including an astronomical object); a mineral, or similar substance; a place, or geographical region; a property of the element; or a scientist (Koppenol et al., 2016).

Some elements are more or less named after their properties. Derived from ancient Greek, chlorine conveys the yellow/green colour of the element, bromine emphasises the unpleasant odour, and iodine notes the violet colour of the vapours. Contradictions and errors in names can reveal changing understanding over time. Rhodium is derived from the Greek ῥόδον *rhodon* "rose" despite being a silver-white metal. Rose more properly names an intermediate substance involved in Wollaston's original synthesis. Molybdenum also has a Greek basis μόλυβδος *molybdos* "lead" revealing the historic confusion between lead and molybdenum ores.

The historical legacy of naming elements includes toponyms; some are derived from celestial bodies, often with a connection to Greek or Roman mythology. Cerium is named after the dwarf planet Ceres (Trofast, 1996), itself named after the Roman goddess of fertility and agriculture. Palladium was named after the asteroid, Pallas, which was named after the Greek goddess Pallas Athena (Griffith, 2004). Although the discoveries of these minor planets were important in the early nineteenth century, few people know the etymological basis of these elements today. In a toponymic example particular to Australia, Josiah Wedgwood FRS, detected a potential new element in a sample of "clay from Sydney Cove" sent to him by Sir Joseph Banks PRS (Wedgwood, 1790). The potential new element became known variously as sydneium and australium amongst other names (Fontani et al., 2014). Further investigation concluded the substance was not a new element. The substance was likely already familiar to the local people. It would be interesting to learn the name of this clay in the local language as a starting point for understanding the substance in more depth.

There is also the issue of divergent naming over time. Beryllium was also called glucinium, especially in the French chemical literature until 1957. Glucinium was chosen because of the sweet taste of this element and some of its compounds; later understanding proved the element was toxic. The elements vanadium and niobium were named panchromium and columbium, but the original discoverers withdrew their claims in the mistaken belief that they had erred in identifying new elements. The niobium/columbium dispute took a century to resolve (Rayner-Canham & Zheng, 2008; Robinson, 2019a). Arguably the biggest controversy over element names has been the so-called Transfermium Wars: the naming of the elements with atomic numbers 104 to 118 (García-Martínez, 2019; Kragh, 2018). They were discovered, often near simultaneously, between 1964 and 2010, by scientists in the United States, Russia, and Germany. National pride led to claims and counterclaims regarding the veracity of the discoveries to determine who could claim naming "rights". Such disputes emphasise how the Periodic Table is a very human manifestation of knowledge and draws attention to the potential for the elements to be understood in a variety of ways depending on the culture and interests involved.

Since 1919, the IUPAC has assumed responsibility for the naming of the elements of the (English) Periodic Table, occasionally in consultation with kindred societies (Robinson, 2019a). The IUPAC has published procedures for the naming of new elements (Koppenol et al., 2016), and the criteria needed to be satisfied to establish the discovery of a new element (Hofmann et al., 2018, 2020). In addition to the historical legacy of a wide range of approaches to naming the elements, the very definition of what constitutes an element remains unsettled. The IUPAC has *two* definitions of an element and the concept of what constitutes an element is debated to this day despite the almost venerable status of the Periodic Table ('Compendium of Chemical Terminology (Gold Book) | IUPAC', 2019; Scerri & Ghibaudi, 2020).

Attempts at a systemised approach to naming the elements have gained little traction (Seidell, 1929), and the fact remains that this is a contested space. The complexity is crucial to appreciate when considering how the elements, and the Table, may be understood in other languages. Many opt for translation, with some bringing the complexity of the English approach to naming elements with them. The Table is today available in about 100 languages, including that of those living on Norfolk Island, one of Australia's external territories (Weber, n.d.), and some element names exist in several languages of Aboriginal peoples ('Australian native languages', n.d.). The complex history of naming elements reveals the contingency at play in the development of the table. Its idiosyncrasies open the path to consider how the elements may be understood in a variety of ways.

In the case that a translation of the elements is considered a viable and productive part of taking a First Nations-first approach, it is useful to understand the strategies others have used to render the elements into an Indigenous language. Four limiting, but not mutually exclusive, strategies include (van der Krogt, n.d.; Stewart, 2010):

- Using an existing elemental name in the Indigenous language
- Using Indigenous language to express a unique characteristic of the element
- Using Indigenous language to express the etymology of the English term
- Borrowing the English term (Sacks, 2001)[3]

In some cases, elements are already named in an Indigenous language. Sulfur is well known in its elemental form in Aotearoa New Zealand, particularly around the sulfurous pools in the North Island. So the Periodic Table in te reo Māori uses the traditional name, *pungatara* (or *pūngāwhā*) for sulfur (Te Tāhuhu o te Mātauranga | Ministry of Education, 2022).

Alternatively, the Indigenous language might exploit the opportunity for the element name to reflect in part the chemistry of that element. In te reo Māori, *helium* is named *haumāmā*, from *hau* (*haurehu*) (gas) and *māmā*, (light, not heavy). Our Canadian cousins suggest *tùḥciti* (fish head) for calcium and *tupàł* (salt water) for sodium (Government of Canada, 2022).

Many of the elements of the Māori Periodic Table use prefixes derived from Māori phrases, combined with a descriptor or context in language. Metals take the prefix *konu* and non-metals using either *hau* or *pu* as prefixes for gases and solids, respectively. By this process, lithium is rendered as *konukōhatu* (a metal from a stone or rock) and chlorine becomes *haumāota* (green gas) (Stewart, 2020).

Borrowing from English or the dominant language of a region can be consistent with established practice over many years and may facilitate pronunciation by using existing phonemes. A variation on this method is to capture the sound of the element name in the local language. Thus, *nickel* is rendered as *nikil* in Kichwa (Andino-Enríquez et al., 2022; Lemonick, 2021), reflecting, in part, the different Kichwa alphabet and drawing upon the Spanish *níquel*. Borrowing may also take the form of the ideas rather than the sounds. Elements might recognise the derivation of the element name in the dominant language of the region. In Kichwa, the name for helium is *intiku*, derived from the Kichwa *inti* (the sun) and *ku* (belongs to) (Andino-Enríquez et al., 2022). However, borrowing from another language can raise questions if culturally specific ideas such as mythological figures are incorporated into a non-western lexicon. For this reason, it may not be the preferred strategy for generating a deep cultural and linguistic understanding that reflects the ideas embedded in the Indigenous language.

These approaches are neither exhaustive nor mutually exclusive; there is no one right way (Government of Canada, 2022). There are several possibilities for rendering the names of the elements in another language. The most important factor is that the choice should be made by the Indigenous community to suit their cultural,

3 We use the term "English", rather than "international", since the latter is incongruous with a Periodic Table available in about 100 languages.

linguistic, and ideological foundations. If we start from a First Nations-first approach, there is potential to understand the elements and the relationships between them in new ways. Aldersey-Williams' observation "I began to perceive that elements told cultural stories" points to a way forward that resonates with Nakata's vision of knowledge creation at the "cultural interface" (Aldersey-Williams, 2012; Nakata, 2007). The cultural interface describes the space between knowledge systems where "things are not clearly black or white, Indigenous or Western" (Nakata, 2007, p. 9).

We seek to celebrate the knowledges, languages, and cultures of the peoples of the Eora nation and those connected with them. To understand the elements more deeply will involve sharing in the liminal space between knowledge systems, engaging in conversations with a view to reaching community consensus, and testing ideas in open forums where local Elders and community members can consider suggested words and phrases and offer advice on how to refine and improve upon the work. The role of chemists is to support the process, provide assistance as it may be sought in regard to the elements themselves, and to engage respectfully at the cultural interface.

4.2 On the shape of the Periodic Table

Just as the naming of elements in the western tradition reveals the history of the development of chemistry, so too does the way that the relationship between the elements is organised through the Periodic Table. The evolution of the Table has been comprehensively described by Scerri (Scerri, 2019), but it is not a settled object, nor are its scientific basis and limitations fully understood (Pyykkö, 2019; Scerri, 2020; Schwarz & Rich, 2010). As more has been learnt, the visual representations used to explain or understand the elements have increased. There are over 1000 representations of the Table including an early nineteenth century three-dimensional helical form (Avenas, 2020; De Chancourtois, 1862; Scerri, 2019), and one in which the elements are not chemicals, but the elements needed to achieve sustainability through green chemistry (Anastas & Zimmerman, 2019; Leach, n.d.; Mazurs, 1974; Scerri, 2019). How best to display the Table remains a matter of debate (Cao et al., 2021; Emsley, 2019; Schwarz et al., 2022).

The different representations of the Table may be seen as celebrations of ingenuity (American Chemical Society, n.d.), however, the choice of representation has been a matter of significant controversy. For example, whether to use an 8-, 10-, 18- or 32- column Table, whether to name the columns in the more familiar 18 column version of the Table 1–18 from left to right, or to name the first two and last six 1A, 2A, 3A…, with the third to twelfth numbered 3B–12B (Zumdahl, 1993), to use Arabic or Latin numerals (Lee, 1991), or to name columns eight, nine and ten, 8B, with columns eleven and twelve named 1B and 2B (Petrucci & Harwood, 1993). Even highly respected contemporary textbooks include several systems for numbering the columns (Weller et al., 2018).[4] Even the concept of numbering the columns has stoked international debate for many years (Robinson, 2019b). Perhaps the ultimate contradiction to the notion of a "settled" Periodic Table are the arguments as to the positioning of the first two elements, hydrogen and of helium (Rayner-Canham, 2020).

Apropos the visual representations of the Periodic Table, Vernon commented, "The first time I saw a 32-column table with a split d-block …. I thought it must have been "wrong" since it appeared so awkward; I later came to realise that I'd subconsciously adopted the Western cultural obsession with symmetry" (Vernon, 2021). This is the salient point. Representations of the Table are as much cultural as they are about the information contained. The visualisation of the elements in the form of a table is a cultural artefact. As such, the Table brings with it assumptions about the relationships between the elements and the nature of the elements. Capturing how the relationship between elements is understood is an important way in which cultural understanding and knowledge systems can be relayed. Part of our work is to step back from this knowledge system and to consider the relationship between elements in the understanding of local knowledge holders. This may include careful demarcations about the elements that are part of daily life, elements that are avoided, and elements that have a

4 This may be a nod to the requirements of different educational jurisdictions. Here, the local New South Wales State Government establishes the secondary school curriculum and provides a Periodic Table for exams with no numbering of the columns.

place in ceremony. Such knowledge may influence how elements are grouped together and how they are represented through visualisation, storytelling, signs, ceremony, dance, or other mechanisms.

5 Knowledges and curricula

Curricula are a means of conveying knowledge. This knowledge comes with assumptions, some of which are cultural in nature. It is usual and appropriate to review curricula to ensure they are fit for purpose and pedagogically sound. Despite the aura of permanence or completeness with which that knowledge can sometimes be transmitted to students, chemistry is an incomplete and changing subject in terms of content and presentation. This is clear from the development of the Periodic Table (Scerri, 2019).

Taking a First Nations-first approach to the elements is an opportunity to reconsider assumptions, both cultural and ideological for generating new knowledge in chemistry. What knowledge is shared, by whom, and for what purpose are key questions for this project. The notion that there are restrictions around some information, some places, and some objects is sometimes referred to as secret/sacred (Janke, 2021, p. 388). Culturally appropriate knowledge sharing will influence the content of any proposed chemistry curriculum that emerges from the work we propose here.

Currently there is a predominance of western perspectives in the ways in which science is generally structured and taught in Australian universities. Chemistry has a reputation as “the central science” with long fingers of influence into many other domains of scientific understanding (Brown et al., 2017). This centrality is part of the reason why it is fundamental to consider how a deeper understanding of culture and cultural heritage can help support the development of the subject. Some parallels can be drawn between this work and the work of colleagues in the global north to decolonise curricula (Dessent et al., 2022), but any process that seeks to redress the consequences of colonialisation will reflect the context in which it takes place and be in some ways unique.[5]

Australia has a historical legacy as a colonial outpost and as a colonial nation today. Australia remains an outlier as there has been no formal treaty reached with Aboriginal and Torres Strait Islander peoples. One legacy of this recent history is the disruption to knowledges and practices. Australia’s history is characterised by violence and silencing and dismissal of Aboriginal and Torres Strait Islander knowledges – scientific or otherwise. Small changes though are apparent throughout the Australian education sector with increasing inclusion of Indigenous knowledges in curricula. At secondary level (12–18 years), the Australian Curriculum, Assessment and Reporting Authority has sought to embed Indigenous knowledges more firmly into the science curriculum (ACARA, n.d.). There is now a strong focus on Indigenous astronomy (physics) at several universities including Western Sydney University, University of Melbourne, and Monash University (‘Aboriginal Astronomy | Western Sydney University’, n.d.; ‘Indigenous Astronomy and Sky Knowledge’, n.d.; ‘Indigenous Astronomy (PHYC10010)’, n.d.). In light of these positive gains, chemistry has much to do. One recent approach in the tertiary space sought to add an Indigenous component into an otherwise unchanged chemistry unit. The results suggest that this is not the most viable way forward as it can position Indigenous knowledges as separate from chemistry and potentially unconnected to it (Ziebell et al., 2021). These results suggest that effective inclusion of Indigenous knowledges requires more than an additive approach to existing curricula.

5.1 Collaborative knowledge creation

Part of the significance of taking a First Nations-first approach in chemistry is understanding the ways in which knowledge can be utilised. Some contrasts with western chemistry can be anticipated. One example is the FAIR

5 For instance, the approach proposed here builds on the thinking around cultural interface proposed by Torres Strait Islander academic Martin Nakata. A similar idea can be seen in the Canadian context with the advocacy for a “Two-Eyed Seeing” approach which brings together an Indigenous lens and a western lens for considering educational reform in STEM (Hogue, 2021, p. 571).

Guiding Principles (Findability, Accessibility, Interoperability, and Reuse) for the reuse of scientific data (Jansen, 2016). In response, the Global Indigenous Data Alliance have developed the CARE Principles (Collective Benefit, Authority to Control, Responsibility, and Ethics) which seeks protections to ensure the ethical use and reuse of data (Global Indigenous Data Alliance, n.d.). There is a clear tension between these approaches to knowledge and data sharing. This tension has often played out to the detriment of Indigenous people. As noted by Janke: "Indigenous people were viewed as only informants or consultants, rather than as scientists and experts, perhaps because their knowledge wasn't acquired through a university degree or in a laboratory" (Janke, 2021, p. 231). There is no simple way through these tensions. Different epistemologies mean that successful collaboration must happen at "the cultural interface" (Nakata, 2007). Torres Strait Islander and academic Martin Nakata acknowledges that new knowledge creation is a potential collaborative way forward, but also notes the inherent challenges "in practical contexts where Indigenous knowledge experts are in direct contact with scientific experts, this is the space of difficult translation between different ways of understanding reality" (Nakata, 2007, p. 9).

This brings us back to our opening question, what can we learn when we take a First Nations-first approach to understanding the elements? By working together with local knowledge holders of the Sydney region and surrounding communities, we seek to understand the chemical elements more deeply. We acknowledge that the Periodic Table is a cultural artefact and recognise its idiosyncrasies. A First Nations-first approach places Aboriginal knowledges at the centre of this work and recognises the importance of Country when it comes to understanding the elements. This work is an opportunity for genuine and respectful learning at the cultural interface. With sharing comes the potential for building an approach to chemistry that honours First Nations-first.

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References

Aboriginal Astronomy | Western Sydney University. (n.d.). https://www.westernsydney.edu.au/campbelltown_observatory/home/areas_of_research_and_teaching/aboriginal_astronomy [Accessed 28 Jan 2022].

ACARA. (n.d.). Aboriginal and Torres Strait Islander histories and cultures. https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/aboriginal-and-torres-strait-islander-histories-and-cultures/ [Accessed 27 Jan 2022].

Aldersey-Williams, H. (2012). *Periodic tales: The curious lives of the elements*. New York: Penguin.

American Chemical Society. (n.d.). American Chemical Society history of the periodic table of the elements. Retrieved from https://www.acs.org/content/dam/acsorg/education/whatischemistry/landmarks/transuranium-elements-at-berkeley-lab/periodic-table-history.pdf

Anastas, P. T., & Zimmerman, J. B. (2019). The periodic table of the elements of green and sustainable chemistry. *Green Chemistry*, *21*(24), 6545–6566.

Andino-Enríquez, J. E., Andino-Enríquez, M. A., Hidalgo-Báez, F. E., Chalán-Gualán, S. P., Gualapuro-Gualapuro, S. D., Belli, S., & Chicaiza-Lema, M. B. (2022). Adaptation of the periodic table to Kichwa: An Ecuadorian native language. *Journal of Chemical Education*, *99*(1), 211–218.

Australian Native Languages. (n.d.). https://canov.jergym.cz/vyhledav/variant7/kreol.htm [Accessed 17 Aug 2022].

Avenas, P. (2020). Les noms des éléments nous racontent leur histoire. *Comptes Rendus. Chimie*, *23*(3), 221–230.

Brown, T., LeMay, H., Bursten, B., Murphy, C., Woodward, P., & Stoltzfus, M. (2017). *Chemistry: The central science* (14th ed.). Harlow, United Kingdom: Pearson Education.

Cao, C., Vernon, R. E., Schwarz, W. H. E., & Li, J. (2021). Understanding periodic and non-periodic chemistry in periodic tables. *Frontiers in Chemistry*, *8*, 813.

Clarkson, C., Jacobs, Z., Marwick, B., Fullagar, R., Wallis, L., Smith, M., … Pardoe, C. (2017). Human occupation of northern Australia by 65,000 years ago. *Nature*, *547*(7663), 30.

Compendium of Chemical Terminology (Gold Book) | IUPAC. (2019). *Compendium of Chemical Terminology*. Browsable online book. Retrieved from https://goldbook.iupac.org/

De Chancourtois, A.-É. B. (1862). Vis tellurique. *Comptes rendus de l'Académie des sciences*, *54*, 757–761.

Department of Climate Change, Energy, the Environment and Water. (n.d.). Australian heritage database. http://www.environment.gov.au/cgi-bin/ahdb/search.pl?mode=place_detail;search=place_name%3DCubbitch%2520Barta%2520National%2520Estate%2520Area%

3Bkeyword_PD%3Don%3Bkeyword_SS%3Don%3Bkeyword_PH%3Don%3Blatitude_1dir%3DS%3Blongitude_1dir%3DE%3Blongitude_2dir%3DE%3Blatitude_2dir%3DS%3Bin_region%3Dpart;place_id=105405 [Accessed 5 Dec 2022].

Department of the Environment and Heritage. (2004). Review of the conservation values of commonwealth land in Western Sydney. Retrieved from https://www.dcceew.gov.au/environment/biodiversity/publications/review-conservation-values-commonwealth-land-western-sydney

Dessent, C. E. H., Dawood, R. A., Jones, L. C., Matharu, A. S., Smith, D. K., & Uleanya, K. O. (2022). Decolonizing the undergraduate chemistry curriculum: An account of how to start. *Journal of Chemical Education*, *99*(1), 5–9.

Eaton, S. E. (2022). New priorities for academic integrity: Equity, diversity, inclusion, decolonization and Indigenization. *International Journal for Educational Integrity*, *18*(1), 1–12.

Emsley, J. (2019). The development of the periodic table and its consequences. *Substantia*, 15–27.

Fontani, M., Costa, M., & Orna, M. V. (2014). The beginning of a long series of scientific blunders. In *The lost elements: The periodic table's shadow side* (pp. 3–17). Oxford University Press. https://academic.oup.com/book/40694/chapter/348407210 [Accessed 17 Aug 2022].

García-Martínez, J. (2019). Controversies, compromises and the common chemical language. *Nature Chemistry*, *11*(10), 853–856.

Global Indigenous Data Alliance. (n.d.). *CARE Principles of Indigenous Data Governance*. Global Indigenous Data Alliance. https://www.gida-global.org/care [Accessed 14 Oct 2022].

Government of Canada, N. S. and E. R. C. of C. (2022). NSERC – science promoters—Connecting traditional knowledge with the periodic table of elements. https://www.nserc-crsng.gc.ca/Promoter-Promotion/ConnectingTraditionalKnowledge-EtablirConnaissancesTraditionnelles/index_eng.asp [Accessed 13 Oct 2022].

Grieves, V. (2008). Aboriginal spirituality: A baseline for indigenous knowledges development in Australia. *The Canadian Journal of Native Studies*, *28*(2), 363–398.

Griffith, W. P. (2004). Bicentenary of four platinum group metals. *Platinum Metals Review*, *47*(4), 182–189.

Hamacher, D., Anderson, G. M., Barsa, J., Bosun, D., Day, R., Passi, S., & Tapim, A. (2022). *The first astronomers: How indigenous elders read the stars*. Sydney, Australia: Allen & Unwin. http://ebookcentral.proquest.com/lib/usyd/detail.action?docID=6888504 [Accessed 17 Aug 2022].

Harrison, R. (2012). *Heritage: Critical approaches*. Milton Park, Abingdon: Taylor & Francis Group.

Hofmann, S., Dmitriev, S. N., Fahlander, C., Gates, J. M., Roberto, J. B., & Sakai, H. (2018). On the discovery of new elements (IUPAC/IUPAP provisional Report): Provisional Report of the 2017 Joint working group of IUPAC and IUPAP. *Pure and Applied Chemistry*, *90*(11), 1773–1832.

Hofmann, S., Dmitriev, S. N., Fahlander, C., Gates, J. M., Roberto, J. B., & Sakai, H. (2020). On the discovery of new elements (IUPAC/IUPAP Report): Report of the 2017 Joint working group of IUPAC and IUPAP. *Pure and Applied Chemistry*, *92*(9), 1387–1446.

Hogue, M. M. (2021). Academic and STEM success: Pathways to indigenous sovereignty. In B. Hokowhitu, A. Moreton-Robinson, L. Tuhiwai-Smith, C. Andersen, & S. Larkin (Eds.), *Routledge handbook of critical indigenous studies* (pp. 566–590). Abingdon: Routledge.

Indigenous Astronomy (PHYC10010). (n.d.). The University of Melbourne Handbook. https://handbook.unimelb.edu.au/2021/subjects/phyc10010 [Accessed 28 Jan 2022].

Indigenous Astronomy and Sky Knowledge. (n.d.). Arts. https://www.monash.edu/arts?a=1669876 [Accessed 28 Jan 2022].

Janke, T. (2021). *True tracks: Respecting indigenous knowledge and culture*. Sydney: New South Publishing.

Jansen, M. (2016). FAIR principles. *GO FAIR*. https://www.go-fair.org/fair-principles/ [Accessed 8 Aug 2022].

Koch, E., & Gillespie, J. (2022). Separating natural and cultural heritage: An outdated approach? *Australian Geographer*, *53*(2), 167–181.

Koppenol, W. H., Corish, J., García-Martínez, J., Meija, J., & Reedijk, J. (2016). How to name new chemical elements (IUPAC Recommendations 2016). *Pure and Applied Chemistry*, *88*(4), 401–405.

Kragh, H. (2018). The Transfermium Wars. In H. Kragh (Ed.), *From transuranic to superheavy elements: A story of dispute and creation* (pp. 59–75). Cham: Springer International Publishing.

van der Krogt, P. (n.d.). Elementymology & elements multidict. https://elements.vanderkrogt.net/index.php [Accessed 4 Aug 2022].

Leach, M. R. (n.d.). The INTERNET database of periodic tables | Chemogenesis. https://www.meta-synthesis.com/webbook/35_pt/pt_database.php [Accessed 3 Aug 2022].

Lee, J. D. (1991). *Concise inorganic chemistry* (4th ed.). London: Chapman & Hall.

Lemonick, S. (2021). Adapting the periodic table into Kichwa. *Chemical & Engineering News*, *99*(43), 4–5.

Martin, K., & Mirraboopa, B. (2003). Ways of knowing, being and doing: A theoretical framework and methods for indigenous and indigenist re-search. *Journal of Australian Studies*, *27*(76), 203–214.

Mazurs, E. G. (1974). *Graphical representations of the periodic system during one hundred years*. Tuscaloosa, Alabama: The University of Alabama Press.

Meija, J. (2021). Politics at the periodic table. *Nature Chemistry*, *13*(9), 814–816.

Nakata, M. (2007). The cultural interface. *The Australian Journal of Indigenous Education*, *36*(S1), 7–14.

Natural Sciences and Engineering Research Council of Canada. (n.d.). Connecting traditional knowledge with the periodic table of elements, (pp. 1–3). https://www.nserc-crsng.gc.ca/Promoter-Promotion/ConnectingTraditionalKnowledge-EtablirConnaissancesTraditionnelles/index_eng.asp [Accessed 13 Dec 2022].

Oliveri, V. A., Porter, G., Davies, C., & James, P. (2022). The Juukan Gorge destruction: A case study in stakeholder-driven and shared values approach to cultural heritage protection. *Journal of Cultural Heritage Management and Sustainable Development*, 1–3. https://doi.org/10.1108/JCHMSD-12-2021-0208 [Epub ahead of print].

Petrucci, R. H., & Harwood, W. S. (1993). *General chemistry. Principles & modern applications* (6th ed.). New York: MacMillan.

Pyykkö, P. (2019). An essay on periodic tables. *Pure and Applied Chemistry*, *91*(12), 1959–1967.

Rayner-Canham, G. (2020). *The periodic table: Past, present, and future*. Singapore: World Scientific Co.

Rayner-Canham, G., & Zheng, Z. (2008). Naming elements after scientists: An account of a controversy. *Foundations of Chemistry*, *10*(1), 13–18.

Riley, L. (2021). Community-led research through an aboriginal lens. In L. Riley, V. Rawlings, & J. L. Flexner (Eds.), *Community-led research*, Walking new pathways together (pp. 9–38). Sydney University Press. https://www.jstor.org/stable/j.ctv1rcf2jj.4 [Accessed 23 Feb 2022].

Robinson, A. E. (2019a). IUPAC and the naming of elements. *Chemistry International*, *41*(3), 44–45.

Robinson, A. E. (2019b). Order from confusion: International chemical standardization and the elements, 1947–1990. *Substantia*, *3*(2) 83–99.

Sacks, O. (2001). *Uncle Tungsten: Memories of a chemical boyhood*. London: Picador.

Scerri, E. (2019). *The periodic table. Its story and its significance* (2nd ed.). New York: Oxford University Press.

Scerri, E. (2020). Recent attempts to change the periodic table. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *378*(2180), 20190300.

Scerri, E., & Ghibaudi, E. (Eds.) (2020). *What is a chemical element? A collection of essays by chemists, philosophers, historians, and educators*. New York: Oxford University Press. http://academic.oup.com/book/36758 [Accessed 4 Aug 2022].

Schwarz, W. H. E., & Rich, R. L. (2010). Theoretical basis and Correct explanation of the periodic system: Review and update. *Journal of Chemical Education*, *87*(4), 435–443.

Schwarz, W. H. E., Müller, U., & Kraus, F. (2022). The good reasons for a standard periodic table of the chemical elements. *Zeitschrift für anorganische und allgemeine Chemie*, *648*(13), 1–10.

Seidell, A. (1929). Limitations upon the unification of chemical nomenclature. *Journal of Chemical Education*, *6*(4), 720.

Stewart, G. (2010). Article commentary: Language issues in Māori chemistry education. *AlterNative: An International Journal of Indigenous Peoples*, *6*(1), 66–71.

Stewart, G. T. (2020). Māori science curriculum. In M. M. Atwater (Ed.), *International handbook of research on multicultural science education* (pp. 1–23). Cham: Springer International Publishing.

Te Tāhuhu o te Mātauranga | Ministry of Education. (2022). Pūtaiao Online. https://putaiao.tki.org.nz/ [Accessed 4 Aug 2022].

Trofast, J. (1996). The discovery of Cerium—A fascinating story. In C. H. Evans (Ed.), *Episodes from the history of the rare earth elements* (Vol. 15, pp. 13–36). Dordrecht: Spring Netherlands.

Troy, J. (2019). *The Sydney language*. Canberra: Aboriginal Studies Press.

Tutt, C. (2021). *The first scientists: Deadly inventions and innovations from Australia's first peoples*. Wurundjeri Country, Richmond, Victoria: Hardie Grant Explore.

Vernon, R. E. (2021). The location and composition of Group 3 of the periodic table. *Foundations of Chemistry*, *23*(2), 155–197.

Weber, K. (n.d.). Norfuk—Pitkern periodic table of the elements. https://canov.jergym.cz/vyhledav/varian34/n_p.htm [Accessed 4 Aug 2022].

Wedgwood, J. (1790). On the analysis of a mineral substance from New South Wales. In a letter from Josiah Wedgwood, esq. F. R. S. and A. S. to Sir Joseph Banks, bart. P. R. S. *Philosophical Transactions of the Royal Society of London*, *80*, 306–320.

Weller, M., Overton, T., Rourke, J., & Armstrong, F. (2018). *Inorganic chemistry* (7th ed.). Oxford: Oxford University Press.

Ziebell, A., Overton, T. L., & Yunkaporta, T. (2021). Australian indigenous knowledge in the undergraduate teaching laboratory. *International Journal of Innovation in Science and Mathematics Education*, *29*(2). https://openjournals.library.sydney.edu.au/index.php/CAL/article/view/15503 [Accessed 24 Feb 2022].

Zumdahl, S. S. (1993). *Chemistry* (3rd ed.). Lexington: D.C. Health and Company.