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Universal Sky, Diverse Cultures

What role for Cultural Astronomy in astronomy education?

Dissertation submitted in partial fulfilment of a
Master of Arts in Cultural Astronomy and Astrology

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Abstract

This research explores the importance and role of cultural astronomy in astronomy education, and the level of attention it has been given in select school-level curricula. Different perspectives on the science–culture divide are reviewed in order to assess whether it is being perpetuated in the context of contemporary astronomy education and in astronomy literacy goals recently set out to inform school curricula, assessment, teacher training, and resource development. Concerns raised around the existence of a universal sky / diverse cultures dichotomy, and whether cultural astronomy could be a promoter of and/or an antidote to ‘universal science’, are also addressed. The conclusion reached is that raising the platform of cultural astronomy education research outside the hierarchy established by modern Western science and developing culturally relevant content that can be taught either independently or embedded in existing school curricula will likely go some way to enriching the field of astronomy as a whole, inspire a lifelong interest in the sky as part of local culture, offer a basis for examining different world views, and potentially attract learners to scientific astronomical enquiry.

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My thanks also go to the Mkhize family, who always kept a watchful eye over me during the years I lived on my smallholding in the foothills of the southern uKhahlamba-Drakensberg in KwaZulu-Natal: Ngiyakukhumbula kanye nesigodi se-eland ngaphezu kokwazi kwakho. The skies there are like no other and the stars 'reach far'.



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1. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Name Hilda J. Hermann

Date 11 April 2021

2. This dissertation is being submitted in partial fulfilment of the requirements for the degree of Master of Arts in Cultural Astronomy and Astrology.

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3. This dissertation is the result of my own independent work/investigation, except where otherwise stated.

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Acronyms

ESD	Education for Sustainable Development
EU-UNAWWE	European Universe Awareness (programme)
IAU	International Astronomical Union
NASA	National Aeronautics and Space Administration
OAE	Office of Astronomy for Education (IAU)
OECD	Organisation for Economic Co-operation and Development
ROSE	Relevance of Science Education (project)
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
UNAWWE	Universe Awareness (programme)
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNPFII	United Nations Permanent Forum on Indigenous Issues

1. Introduction

A respondent in Sanlyn Buxner and Shawna Holbrook's research on integrating African cultural astronomy into the classroom suggested that 'one way to destroy local culture was to talk about the universality of the sky ... and that this way of thinking would destroy cultural diversity'.¹ This idea appears to be upheld in a review of Organisation for Economic Co-operation and Development (OECD) school curricula, including China and South Africa, published in 2020, in which Saeed Salimpour, et al. concluded that there was 'a lack of explicit mention about astronomy from a cultural or indigenous perspective'.² Salimpour, et al. went on to comment: 'This is disheartening as astronomy could be an exciting way to engage indigenous students and start classroom conversations between different world views' and that this 'would potentially boost students' engagement with, and appreciation of, science'.³ Some ten years earlier, the Relevance of Science in Education (ROSE) project had identified country-specific differences in learners' attitudes to and motivations for learning science, particularly between so-called 'developed' and 'developing countries', and reached the conclusion that science education should be contextualised, and that there appeared to be 'a need to "humanize" school science, to show that science is part of human history and culture, and that it is a corner-stone in our present, modern world-view'.⁴

Big Ideas in Astronomy: A Proposed Definition of Astronomy Literacy forms part of the International Astronomical Union's (IAU) Strategic Plan 2020–2030, which 'places astronomy education at the core of the global astronomy endeavour'.⁵ The purpose behind

¹ Sanlyn Buxner and Shawna Holbrook, 'Integrating African Cultural Astronomy into the Classroom', in *African Cultural Astronomy: Current archaeoastronomy and ethnoastronomy research in Africa*, ed. by Jarita Holbrook, Rodney Medupe and Johnson Urama (Dordrecht: Springer Science+Business Media BV, 2008), pp. 88–89.

² Saeed Salimpour, Sophie Bartlett, Michael T. Fitzgerald, David H. McKinnon, K. Ross Cutts, C. Renee James, Scott Miller, Lena Danaia, Robert P. Hollow, Sergio Cabezon, Michel Faye, Akihiko Tomita, Charles Max, Michael de Korte, Cyrille Baudouin, Daina Birkenbauma, Maria Kallery, Sara Anjos, Qixuan Wu, Hye-eun Chu, Eileen Slater and Amelia Ortiz-Gil, 'The Gateway Science: A Review of Astronomy in the OECD School Curricula, Including China and South Africa', *Research in Science Education*, (March 2020), p. 19, https://www.researchgate.net/publication/339840321_The_Gateway_Science_a_Review_of_Astronomy_in_the_OECD_School_Curricula_Including_China_and_South_Africa [accessed March 25, 2021].

³ Salimpour, et al., 'The Gateway Science', p. 19.

⁴ Sven Sjøberg and Camilla Schreiner, 'The ROSE Project: Overview and key findings', (2010), <https://roseproject.no/network/countries/norway/eng/nor-Sjoberg-Schreiner-overview-2010.pdf> [accessed March 25, 2021].

⁵ João Retrê, Pedro Russo, Hyunju Lee, Eduardo Penteado, Saeed Salimpour, Michael Fitzgerald, Jaya Ramchandani, Markus Pössel, Cecilia Scorza, Lars Lindberg Christensen, Erik Arends, Stephen Pompea

defining these Big Ideas is to inform school curricula, assessment, teacher training, and resource development. However, there is a need to question the importance and role of cultural astronomy, which is rooted in the language and culture of a place, and the level of attention it is being given in current ‘universal’ science-focused curricula. I will therefore:

1. Consider whether a historical science–culture divide is being perpetuated in astronomy education and if this is contributing to a universal sky / diverse cultures dichotomy;
2. Investigate the importance and role of cultural astronomy in astronomy education, and whether it could be a promoter of and/or antidote to ‘universal’ science; and
3. Review the IAU’s *Big Ideas in Astronomy* in the context of the research findings.

2. Methodology

The research methodology comprised secondary (desk) research, making use of existing primary and secondary sources. These included published peer-reviewed research papers, doctoral theses, policy documents, strategic plans and books that are available through university libraries and repositories, international organisation and agency websites, and academic publishers. The aim of using this type of research was to gain a broad understanding of the subject matter based on authentic narrative and previously verified data.

This study focused on science and astronomy education for learners up to the age of 15 in formal schooling, in line with recent research in this field by Svein Sjøberg and Camilla Schreiner (2010), Saeed Salimpour, et al. (2020), and Annette Lee (2020).⁶

and Wouter Schrier, *Big Ideas in Astronomy: A proposed definition of astronomy literacy* (IAU, 2019), <https://www.iau.org/static/archives/announcements/pdf/ann19029a.pdf> [accessed March 25, 2021]; IAU, *IAU Strategic Plan 2020–2030*, https://www.iau.org/static/administration/about/strategic_plan/strategicplan-2020-2030.pdf [accessed March 25, 2021].

⁶ Sjøberg and Schreiner, ‘The Rose Project’; Salimpour, et al., ‘The Gateway Science’; Annette S. Lee, ‘The effects on student knowledge and engagement when using a culturally responsive framework to teach ASTR 101’ (DPhil thesis, Department of Physics and Astronomy, University of the Western Cape, South Africa, 2020).

3. Literature review

Issues involving modern Western science, the arts and humanities, and indigenous/traditional knowledge are central to situating this research as they provide both the historical background and current frameworks for addressing the inclusion of cultural astronomy in astronomy education.

3.1 The science–culture divide

According to British philosopher Mary Midgley, the effectiveness of René Descartes' 'reduction of other sciences to mathematics via physics' in the seventeenth century, was an agenda that later became what Auguste Comte 'proclaimed as part of the gospel of positivism ... which Victorian intellectuals welcomed as a way of cutting out the metaphysical extravagances of religion'.⁷ Midgley also suggested that determinism enabled specialists to develop a type of unilateral 'tribal narrowness', which arranged different ways of thinking in a linear, superficial-to-fundamental hierarchy.⁸ She then raised concern that academic narrowness was as much way of life as any other, and that it was 'easily conveyed by a style of writing, and even more easily by a style of teaching'.⁹

In 1956, British physicist and novelist C.P. Snow set out his preliminary thoughts on the 'two cultures' ('science' and 'the arts'), which he later expanded on in his 1959 Rede Lecture to Cambridge University.¹⁰ He suggested that Western society was becoming increasingly polarised, with 'literary intellectuals at one pole – at the other scientists, and as the most representative, the physical scientists'.¹¹ Describing their apparent mutual incomprehension to the point of contempt, Snow claimed that, 'If the scientists have the future in their bones, then the traditional culture responds by wishing the future did not exist', which indicated that there may be no meeting point between the two cultures.¹² This divide continued to be reinforced in the mid-1990s, when British scientist Peter Atkins argued that science was omniscient and that the arts and humanities had contributed little to an understanding of the universe, adopting the adage 'while poetry

⁷ Mary Midgley, *Science and Poetry* (London: Routledge, 2001), pp. 116-117.

⁸ Midgley, *Science and Poetry*, pp. 118, 119, 120.

⁹ Midgley, *Science and Poetry*, p. 39.

¹⁰ C.P. Snow, 'The Two Cultures', *New Statesman*, 6 October 1956; C.P. Snow, *The Two Cultures and The Scientific Revolution: The Rede Lecture 1959* (New York: Cambridge University Press, 1961 [1959]).

¹¹ Snow, *The Two Cultures*, p. 4.

¹² Snow, *The Two Cultures*, pp. 4, 8, 12, 17.

titillates and theology obfuscates, science liberates'.¹³ However, Midgley noted that it was Roman poet Lucretius' philosophic poem *De Rerum Natura* (*On the Nature of the Universe*) that conveyed the atomic theory of matter to Renaissance Europe and influenced the formation of modern Western thought, and particularly Western science.¹⁴ Writing about the social and cultural history of physics, Margaret Wertheim has commented that, despite the secular climate of modern science, physicists retained 'a quasi-religious attitude to their work [and] continued to comport themselves as a scientific priesthood, and to present themselves to the public in that light'.¹⁵

Snow suggested that, although the science–culture divide existed throughout the Western world, it was specific in England [sic] because of the 'fanatical belief in educational specialisation'.¹⁶ He went on to state that once a cultural divide takes hold it becomes rigid, and that the only solution to this impasse was to rethink education.¹⁷ For Midgley, though, it was the 'strange, imperialistic, isolating ideology about science' that made its connection with culture seem impossible, and she argued that taking an 'anti-science' stance was a protest against imperialism, which extended impersonal, reductive and atomistic methods to social and psychological enquiry.¹⁸ However, she also pointed out that 'all science grows out of philosophical thinking', and that it was the arts that provided 'the language in which our imaginative visions are most immediately articulated'.¹⁹

In her 2010 Rede Lecture, 'The Two Cultures Fifty Years On', British philosopher Onora O'Neill suggested that Snow may have adopted positivists' claims as she could identify no fissure separating the work of the 'empirical' natural sciences from that of the 'reflective or interpretive' humanities, as both forms of inquiry made use of the same methods.²⁰ That said, some commentators insist science is an exemplar of objectivity and a universal truth devoid of culture, with scholars such as American philosopher Sandra Harding having argued as recently as 2016 that science is embedded in Western ethnocentrism and 'only practitioners of Western scientific rationality exercise critical

¹³ Peter Atkins, 'The Limitless Power of Science', in *Nature's Imagination: Frontiers of scientific vision*, ed. by John Cornwell (Oxford: Oxford University Press, 1995), p. 123.

¹⁴ Midgley, *Science and Poetry*, p. 23.

¹⁵ Margaret Wertheim, *Pythagoras' Trousers* (London: Fourth Estate, 1997), p. 12.

¹⁶ Snow, *The Two Cultures*, p. 18.

¹⁷ Snow, *The Two Cultures*, p. 19.

¹⁸ Midgley, *Science and Poetry*, p. 1.

¹⁹ Midgley, *Science and Poetry*, pp. 36, 38.

²⁰ Onora O'Neill, 'Two cultures fifty years on', in *From Principles to Practice: Normativity and judgement in ethics and politics* (Cambridge: Cambridge University Press, 2018), pp. 150, 151, 155.

reason'.²¹ However, South African academic Lesley le Grange has commented that, while the meaning of science has undergone significant transformation from 'mastery of learning' to 'measuring falsifiable truths', the meaning of physics has shifted more dramatically from 'philosophy of nature' to 'fundamental laws of the material universe', indicating that science has layers of what he has suggested are 'cultural fingerprints'.²²

Additionally, Le Grange has noted that the criteria used to define Western science are also used to declare 'other' knowledges as non-science.²³ These 'other' knowledges refer to indigenous knowledge and, in the context of Western astronomy, is extended to astrology, which has been labelled a pseudoscience.²⁴ Halil Turgut, however, highlighted that demarcation (the criteria that differentiate science from non-science and pseudoscience) has been a central issue of philosophies of science that has remained unresolved since the early 1900s, and surmised that no criterion or criteria could 'undisputedly serve to qualify an activity as science and hence demarcate it'.²⁵

Although Bryan Brayboy and Angeline Castagno proposed that the assumed objectivity and universalism of Western science, in service of the dominant culture, has rationalised our failure to recognise other ways of knowing, Lee indicated that indigenous knowledge and curriculum reform is an area of contemporary research, particularly in terms of science education and decolonising science.²⁶ Gregory Cajete's research on native science and education informed his assertion that the Western world view is a 'dysfunctional cosmology' that requires indigenous knowledge to redress its individualistic and capitalistic culture.²⁷ Specifically:

Western science has often been caught up in an almost fanatic drive to objectify and fragment all of human experience so that it could somehow be better or more clearly understood or controlled. But these methodologies

²¹ Sandra Harding, *Whose Science? Whose Knowledge?: Thinking from Women's Lives* (New York: Cornell University Press, 2016), p. 98.

²² Lesley le Grange, 'Integrating Western and Indigenous Knowledge Systems: The basis for effective science education in South Africa?', *International Review of Education*, 53 (2007), p. 586.

²³ Le Grange, 'Integrating Western and Indigenous Knowledge Systems', p. 586.

²⁴ Retrê, et al., *Big Ideas in Astronomy*, p. 20.

²⁵ Halil Turgut, 'The Context of Demarcation in Nature of Science Teaching: The case of astrology', *Science & Education*, 20 (2011), pp. 494, 498.

²⁶ Bryan McKinley Jones Brayboy and Angelina E. Castagno, 'How might Native science inform "informal science learning"', *Cultural Studies of Science Education*, 3 (2008), p. 738; Lee, 'The effects on student knowledge and engagement', p. 14.

²⁷ Gregory A. Cajete, *Native Science: Natural laws of interdependence*. (Santa Fe, NM: Clear Light Publishers, 2000), pp. 53, 307.

often forget to recontextualize data bits, or to recycle that knowledge into a meaningful expression for human life and human situations. Indigenous science is a process of thinking and relating that refuses to decontextualize.²⁸

However, Charbel El-Hani and Fábio Bandeira have suggested that if indigenous knowledge has its own epistemic criteria, which indicates its value and legitimacy in its own right, calling it ‘science’ will likely contribute to removing it from the context in which it finds its legitimacy.²⁹ Moyra Keane has also drawn attention to the fact that indigenous knowledge is not a single concept and is not always public, and therefore ‘not meant to be teased into categories and definitions by academics’.³⁰

3.2 Science–culture and global agencies

The United Nations Educational, Scientific and Cultural Organization (UNESCO), founded in 1945, claims to work ‘to create the conditions for genuine dialogue between civilizations, cultures and peoples based upon mutual respect and respect for shared values’.³¹ It sets out its definition of local and indigenous knowledge as:

...the understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For rural and indigenous peoples, local knowledge informs decision-making about fundamental aspects of day-to-day life. This knowledge is integral to a cultural complex that also encompasses language, systems of classification, resource use practices, social interactions, ritual and spirituality. These unique ways of knowing are important facets of the world’s cultural diversity, and provide a foundation for locally-appropriate sustainable development.³²

One might anticipate that this definition would be nested in ‘Culture’, but instead it is framed as a priority area of science policy, biodiversity, climate change and knowledge transmission.³³ However, according to the United Nations Permanent Forum on Indigenous Issues (UNPFII), founded in 2000, there are more than 370 million indigenous

²⁸ Cajete, *Native Science*, p. 307.

²⁹ Charbel Nino El-Hani and Fábio Pedro Souza de Ferreira Bandeira, ‘Valuing indigenous knowledge: To call it “science” will not help’, *Cultural Studies of Science Education*, 3 (2008), p. 763.

³⁰ Moyra Keane, ‘Science education and worldview’, *Cultural Studies of Science Education*, 3 (2008), p. 590.

³¹ UNESCO, ‘Mission and Strategy’, <http://www.unesco.org/new/en/natural-sciences/about-us/how-we-work/mission-strategy/> [accessed March 25, 2021].

³² UNESCO, ‘What is Local and Indigenous Knowledge?’, <http://www.unesco.org/new/en/natural-sciences/priority-areas/links/related-information/what-is-local-and-indigenous-knowledge> [accessed March 25, 2021].

³³ UNESCO, ‘Mission and Strategy’.

people across 70 countries who practice their unique traditions and ‘retain social, cultural, economic and political characteristics that are distinct from those of the dominant societies in which they live’.³⁴ That said, UNESCO has acknowledged that traditional and local knowledge systems can, and have historically made, a valuable contribution to science and technology, which may indicate, as Lee has suggested, that ‘UNESCO understands the importance of widening the lens of science’.³⁵ Yet the National Aeronautics and Space Administration (NASA) retains a limited definition of astronomy as: ‘The scientific study of matter in outer space, especially the positions, dimensions, distribution, motion, composition, energy, and evolution of celestial bodies and phenomena’.³⁶ In terms of situating astronomy in modern society, this definition appears to be at odds with comments made by Clive Ruggles who, referencing a statement on astronomy embodying a unique combination of science, technology and cultures in the IAU’s Strategic Plan 2010–2020, noted:

...in the context of many peoples of the world, and particularly within developing nations, the ‘astronomy’ that continues to play an important cultural role ... is not modern scientific or (for want of a better term) ‘Western’ astronomy. In such contexts, there are innate hurdles on the path towards even the acceptance, let alone better comprehension and contribution to the advancement, of modern scientific astronomy. One of the prerequisites is that ‘Western’ astronomers attempting to communicate ‘their’ astronomy must acknowledge and respect the importance of these indigenous astronomies; and greater respect can only come from a greater degree of comprehension.³⁷

3.3 Science education

In this section, I will consider literature on: how science is currently defined; the research on the relevance of science education conducted by the ROSE project and how this relates

³⁴ UNPFII, ‘Who are indigenous peoples?’, https://www.un.org/esa/socdev/unpfii/documents/5session_factsheet1.pdf [accessed March 25, 2021].

³⁵ UNESCO, ‘Declaration on science and the use of scientific knowledge’ (World Conference on Science: Science for the Twenty-First Century, Budapest, Hungary, 26 June–1 July 1999), p. 9, <https://unesdoc.unesco.org/ark:/48223/pf0000122938?posInSet=1&queryId=a47e6c2d-1f23-4944-882f-a6febd22f9cd> [accessed March 25, 2021]; Lee, ‘The effects on student knowledge and engagement’, p. 15.

³⁶ NASA, Imagine the Universe! Dictionary (online), <https://imagine.gsfc.nasa.gov/resources/dictionary.html#A> [accessed March 25, 2021].

³⁷ Clive Ruggles, ‘Indigenous astronomies and progress in modern astronomy’, *Proceedings of Science*, PoS(sps5)029 (2010), p. 2. The report to which Ruggles referred is the *IAU Strategic Plan 2010–2020*, p. 9, https://iau.org/static/education/strategicplan_2010-2020.pdf [accessed March 25, 2021].

to astronomy education; and the inclusion of the arts in science, technology, engineering and mathematics (STEM) education.

3.3.1 Defining 'science'

In the historical record, and as noted by Le Grange, the etymology of 'science' has shifted over time from a philosophy of nature to a mechanistic Cartesian model.³⁸ In 2009, the UK-based Science Council (of which the Royal Astronomical Society is a member) revised its definition of science to: 'The pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence'.³⁹ However, as historian David Edgerton pointed out, this definition refers to science as an activity related to the creation of new knowledge rather than established knowledge.⁴⁰ He argued, as had O'Neill, that science is not demarcated from the humanities, and that a definition of science needs to 'define the nature of the knowledge [and] not the means of its creation only', which he suggested was something the Science Council appeared to have overlooked.⁴¹

3.3.2 Relevance of science education

Sjøberg and Schreiner's Relevance of Science Education (ROSE) project (2001–2004), which received core funding from The Research Council of Norway, gathered data from 40 countries to investigate factors that affected learners' attitudes and motivations to learn science and technology.⁴² These factors included out-of-school experiences, interests, prior experiences and views on school science, and views and attitudes to science and scientists.⁴³

³⁸ Oxford English Dictionary (online), 'Science', <https://www.oed.com/oed2/00215815> [accessed March 25, 2021]; Le Grange, 'Integrating Western and Indigenous Knowledge Systems', p. 586.

³⁹ Science Council, 'Our definition of science', <https://sciencecouncil.org/about-science/our-definition-of-science/> [accessed March 25, 2021].

⁴⁰ Ian Sample, 'What is this thing we call science?', *The Guardian*, 4 March 2009, <https://www.theguardian.com/science/blog/2009/mar/03/science-definition-council-francis-bacon> [accessed March 25, 2021].

⁴¹ Ian Sample, 'What is this thing we call science?'; O'Neill, 'Two Cultures Fifty Years On', pp. 150, 151, 155.

⁴² Svein Sjøberg and Camilla Schreiner, 'ROSE (The Relevance of Science Education). The development, key findings and impacts of an international low cost comparative project. Final Report, Part 1 (of 2)' (2019), p. 5, https://www.researchgate.net/publication/335664683_ROSE_The_Relevance_of_Science_Education_The_development_key_findings_and_impacts_of_an_international_low_cost_comparative_project_Final_Report_Part_1_of_2 [accessed March 25, 2021]; Sjøberg and Schreiner, 'The Rose Project', p. 5.

⁴³ Sjøberg and Schreiner, 'The Rose Project', p. 5.

The ROSE project limited its enquiry to children up to the age of 15 in the formal school system, pointing out that educational considerations for higher levels differ from those of ‘obligatory school’, and referring to science as an optional, chosen subject ‘for the rather few’.⁴⁴ Sjøberg and Schreiner noted that early-stage science curricula tend to be based on an assumption that school science is the first step in the process of educating future scientists and that, while this may appear logical from a scientific standpoint, it was unlikely to engage the majority of children.⁴⁵ They suggested that, because the contexts of learners vary widely from country to country, science curricula (at this age) needed to be ‘humanised’ and ‘cannot and should not strive to be common and universal’.⁴⁶ As such, ‘localising the curriculum’ would meet the need for science and technology to be contextualised, which they indicated was grounded in the theoretical contexts of constructivism, situated learning and socio-cultural theory.⁴⁷

To inform how science education could be made relevant and meaningful, a questionnaire was developed to map 15-year-old learners’ attitudinal and affective perspectives on science and technology.⁴⁸ Of the 106 items on various science learning areas, only 19 aligned with astronomy from a scientific and/or cultural perspective (Table 1, p. 16).⁴⁹

Data indicated that interest was context-dependent and that there was less interest in the topics ordinarily covered in science curricula and textbooks.⁵⁰ Although a strong gendering of interests was identified, the most popular interest among all learners was ‘The possibility of life outside earth – “Space, life, wonder, openness”’.⁵¹ A negative correlation between average interest and level of development (as determined by the Human Development Index) was noted, but Sjøberg and Schreiner asserted this did not mean that children in developed countries were less interested in science.⁵² Rather, attending school at age 15 in developing countries was seen as a privilege and learners were ‘happy to learn about nearly everything the school may offer’.⁵³

⁴⁴ Sjøberg and Schreiner, ‘The Rose Project’, p. 4.

⁴⁵ Sjøberg and Schreiner, ‘The Rose Project’, p. 30.

⁴⁶ Sjøberg and Schreiner, ‘The Rose Project’, p. 29.

⁴⁷ Sjøberg and Schreiner, ‘The Rose Project’, p. 29.

⁴⁸ Sjøberg and Schreiner, ‘The Rose Project’, p. 5.

⁴⁹ ROSE, ‘The ROSE questionnaire’, <https://roseproject.no/key-documents/questionnaire.html> [accessed March 25, 2021].

⁵⁰ Sjøberg and Schreiner, ‘The Rose Project’, pp. 16, 19.

⁵¹ Sjøberg and Schreiner, ‘The Rose Project’, pp. 19, 21.

⁵² Sjøberg and Schreiner, ‘The Rose Project’, p. 16.

⁵³ Sjøberg and Schreiner, ‘The Rose Project’, p. 16.

Table 1: Topics associated with astronomy in the ROSE questionnaire (with original questionnaire section and item numbering retained).

Section A <i>What I want to learn about:</i> 1. Stars, planets and the universe 22. Black holes, supernovas and other spectacular objects in outer space 23. How meteors, comets or asteroids may cause disasters on earth 34. How it feels to be weightless in space 35. How to find my way and navigate by the stars 44. Rockets, satellites and space travel 45. The use of satellites for communication and other purposes	Section C <i>What I want to learn about:</i> 2. Optical instruments and how they work (telescope, camera, microscope, etc.) 8. The possibility of life outside earth 9. Astrology and horoscopes, and whether the planets can influence human beings 10. Unsolved mysteries in outer space 16. Why the stars twinkle and the sky is blue
Section E <i>What I want to learn about:</i> 2. How the sunset colours the sky 29. The first landing on the moon and the history of space exploration 34. Why religion and science sometimes are in conflict 39. How scientific ideas sometimes challenge religion, authority and tradition 40. Inventions and discoveries that have changed the world	Section H (out-of-school experiences) <i>How often have you done this outside school?</i> 1. Tried to find the star constellations in the sky 2. Read my horoscope (telling future from the stars)

Sjøberg and Schreiner concluded that European and other OECD countries faced serious recruitment issues in science and technology, with a low proportion of girls choosing to take up careers in this sector a particular concern.⁵⁴ However, the ROSE project's data suggested that if science, mathematics and technology school curricula were extended to caring for the environment and addressing social values, this may contribute to improving the gender balance.⁵⁵ They went on to stress that a revision of priorities would not imply a 'watered-down' version of 'real science', but rather that society would be better served if its relevance was recognised.⁵⁶

3.3.3 A shift from STEM to STEAM

According to Australian academic Peter C. Taylor, science, technology, engineering and mathematics (STEM) educators are being challenged to design curricula aligned with

⁵⁴ Sjøberg and Schreiner, 'The Rose Project', pp. 28, 30.

⁵⁵ Sjøberg and Schreiner, 'The Rose Project', p. 30.

⁵⁶ Sjøberg and Schreiner, 'The Rose Project', p. 30.

UNESCO's education for sustainable development (ESD) priorities.⁵⁷ The pedagogical techniques of ESD include the promotion of participatory learning and higher-order thinking skills, and lifelong learning; local relevance and cultural appropriateness; formal, non-formal and informal education; conveying content inclusive of context, global issues and local priorities; and interdisciplinarity.⁵⁸

In the Australian science curriculum, teachers must engage learners in not only developing a range of scientific concepts and inquiry skills, but also the dimension of science as a human endeavour, which they suggest 'opens the door to understanding the nature and limitations of science and to considering the cost to the planet and to humanity of [its] unintended side-effects'.⁵⁹ Taylor suggested that, while the clearest evidence of our detrimental impact on Earth is climate change, the loss of linguistic, cultural and biological diversity was also significant, albeit less well embedded in public consciousness.⁶⁰

The shift to a STEAM (STEM + Arts) curriculum philosophy, as Taylor indicates, engages learners in transformative learning based on five interconnected ways of knowing: cultural self-knowing, relational knowing, critical knowing, visionary and ethical knowing, and knowing in action.⁶¹ STEAM curricula have also resulted in minority and disadvantaged learners becoming more engaged and improving their competency in literacy and numeracy.⁶² Similarly, Bronwen Wade-Leeuwen, et al. contend that STEAM challenges the preconception of separate learning areas and enables learners to move past an 'I'm not good at science' or 'I'm not creative' mind-set towards ways of thinking that are 'engaging, multifaceted and inclusive, with diversity of

⁵⁷ Peter C. Taylor, 'Why is a STEAM curriculum perspective crucial to the 21st century?' (paper presented at the ACER Research Conference 2016: Improving STEM Learning: What will it take?, Brisbane, Australia, 7-9 August 2016), p.1; UNESCO, 'What is Education for Sustainable Development?', <https://en.unesco.org/themes/education-sustainable-development/what-is-esd> [accessed March 25, 2021].

⁵⁸ Taylor, 'Why is a STEAM curriculum perspective crucial to the 21st century?', p. 3; UNESCO, 'Education for sustainable development', <http://www.unesco.org/new/en/education/themes/leading-the-international-agenda/education-for-sustainable-development/education-for-sustainable-development> [accessed March 25, 2021].

⁵⁹ Taylor, 'Why is a STEAM curriculum perspective crucial to the 21st century?', p. 2.

⁶⁰ Taylor, 'Why is a STEAM curriculum perspective crucial to the 21st century?', p. 2.

⁶¹ Taylor, 'Why is a STEAM curriculum perspective crucial to the 21st century?', p. 4; Peter C. Taylor, 'Transformative science education', in *Encyclopedia of Science Education*, ed. by Richard Gunstone (Dordrecht: Springer, 2015), pp. 1079-1082.

⁶² Taylor, 'Why is a STEAM curriculum perspective crucial to the 21st century?', p. 4.

representation and thought'.⁶³ However, this means that teachers must be equipped to provide learners with interdisciplinary, multicultural and multi-perspective viewpoints.⁶⁴

In the next section, I will look at the IAU's position on astronomy education as set out in its Strategic Plan 2020–2030, alongside research by Salimpour, et al. on astronomy as the 'gateway science' and by Lee on culturally responsive astronomy education.⁶⁵

3.4 Astronomy education

Apart from focusing on the advancement of astronomy through stimulating and disseminating astronomical knowledge and producing the next generation of astronomers, the IAU also lays claim to 'safeguarding the science of astronomy'.⁶⁶ According to its Strategic Plan 2020–2030, the IAU's involvement in education and history dates back to the 1970s, while its participation in outreach and heritage has been concentrated only over the last decade.⁶⁷ Whereas it has pledged to strengthen these areas, which are considered 'important in order for astronomy to be appreciated and supported by the public', they are overtly referred to as non-scientific aspects of the IAU's mission.⁶⁸

Five strategic goals and eight priority areas have been identified in the Strategic Plan 2020–2030 (summarised in Appendix I). For this research, I will focus on Goal 5: 'The IAU stimulates the use of astronomy for teaching and education at school level'.

The remit of the IAU's Education, Outreach and Heritage division (Division C) includes the promotion of education at all levels – primary, tertiary, formal, and informal – as guided by astronomy education research, and the promotion of astronomy in developing countries.⁶⁹ The division's involvement with heritage relates to the 'legacy of astronomical artefacts and structures as well as the astronomical attributes of mankind's [sic] cultural history', while mention is also made of close interactions with UNESCO.⁷⁰

⁶³ Bronwen Wade-Leeuwen, Jessica Vovers and Melissa Silk, 'Explainer: What's the difference between STEM and STEAM?', *The Conversation*, 10 June 2018, <https://theconversation.com/explainer-whats-the-difference-between-stem-and-steam-95713> [accessed March 25, 2021].

⁶⁴ T.J. Kennedy and M.R.L. Odell, 'Engaging Students in STEM Education', *Science Education International*, 25:3 (2014), p. 256.

⁶⁵ IAU, *IAU Strategic Plan 2020–2030*; Salimpour, et al., 'The Gateway Science'; Lee, 'The effects on student knowledge and engagement'.

⁶⁶ IAU, *IAU Strategic Plan 2020–2030*, p. 4.

⁶⁷ IAU, *IAU Strategic Plan 2020–2030*, p. 51.

⁶⁸ IAU, *IAU Strategic Plan 2020–2030*, p. 51.

⁶⁹ IAU, *IAU Strategic Plan 2020–2030*, pp. 50, 51.

⁷⁰ IAU, *IAU Strategic Plan 2020–2030*, pp. 50, 51.

The division also has an interest in maintaining dark skies in terms of the impact on education, outreach and research.⁷¹

According to the IAU, ‘the enterprise of astronomy is integral to the human drive to explore and understand the world around us’, and ‘the quest to examine the evolution of the Universe is an endeavour that unites all countries, for we are bound by the common goal of making sense of our place on Earth’.⁷² It then explicitly states that ‘because of its broad appeal, astronomy is a gateway science that opens the world of possibilities to all, by nurturing inquisitiveness and the pursuit of knowledge using the scientific method’.⁷³ However, the idea of astronomy as a gateway science is currently under review, and is discussed further in section 3.4.1.⁷⁴

As set out in its Strategic Plan 2020–2030, the ambit of the IAU has evolved from being focused primarily on scientific activities to ‘furthering sustainable global development and addressing global societal challenges’, which, it has suggested, can only be accomplished through the commitment and efforts of its members and by ‘building bridges with other disciplines’.⁷⁵ Although ‘Culture and Society’ appears as a category in the IAU’s illustration of astronomy’s connection with other disciplines (Figure 1, p. 20), it is only referenced generically in the strategic plan, and the terms ‘traditional’ and/or ‘indigenous’ are notably absent.

It is worth noting that there are multiple academic barriers to membership of the IAU, although it makes an apparent concession in recognition of the increasingly multidisciplinary nature of astronomy that ‘PhD scientists whose primary research is in other fields but who make important contributions to astronomy will be eligible to become Associate Members, and non-PhDs whose work is relevant to astronomy can occasionally become Associate Members through Divisions, Commissions, and Working Groups’.⁷⁶

⁷¹ IAU, *IAU Strategic Plan 2020–2030*, p. 51.

⁷² IAU, *IAU Strategic Plan 2020–2030*, p. 7-8.

⁷³ IAU, *IAU Strategic Plan 2020–2030*, pp. 7-8.

⁷⁴ Salimpour, et al., ‘The Gateway Science’.

⁷⁵ IAU, *IAU Strategic Plan 2020–2030*, p. 44.

⁷⁶ IAU, *IAU Strategic Plan 2020–2030*, p. 17.

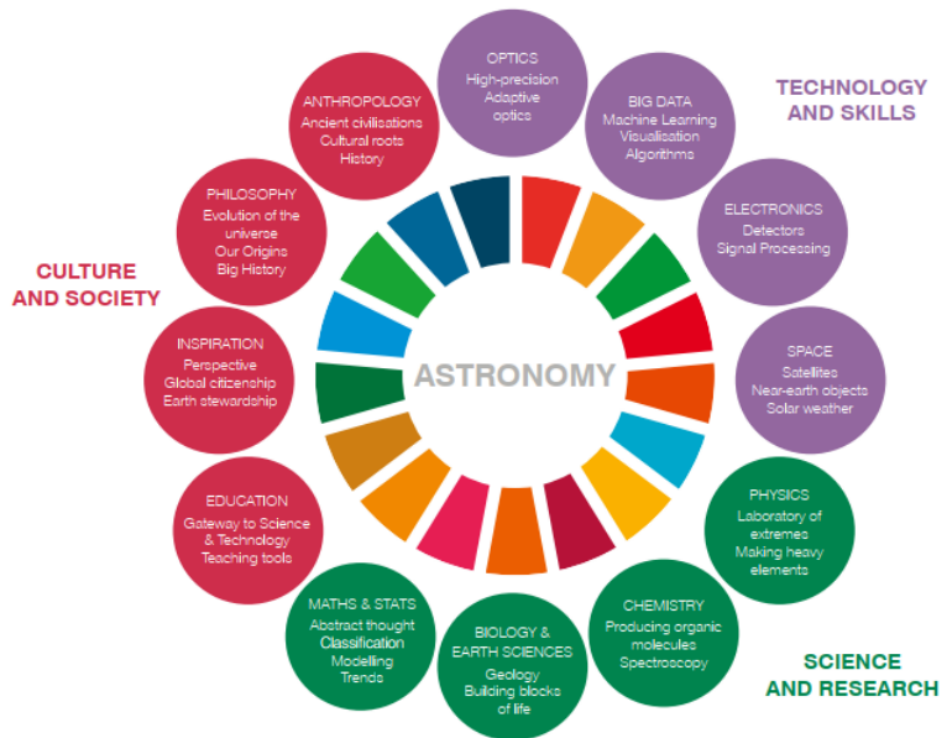


Figure 1: Astronomy's connection with other disciplines. The colours of the inner ring correspond with those of the United Nations' Sustainable Development Goals. (Source: *IAU Strategic Plan 2020–2030*, p. 22 (CC BY 4.0))

The IAU's divisions, commissions and working groups, which may be seen as reminiscent of Wertheim's description of a 'scientific priesthood' (p. 10) and reflective of Snow's critical references to educational specialisation (p. 10), are made up of 'professional astronomers from all over the world, at the PhD level and beyond, who are active in professional research, education and outreach in astronomy'.⁷⁷ However, the IAU states that 'as the worldwide astronomy organisation [it has] 79 member nations and members from 101 countries', which translates to only 40.5% and 51.7% respectively of a total of 195 countries.⁷⁸ This raises issues around representation – markedly so of many African countries which reflect no nation or individual membership – which is visually indicated in the IAU's map of membership by gender and geography (Figure 2, p. 21).⁷⁹

⁷⁷ IAU, *IAU Strategic Plan 2020–2030*, p. 3.

⁷⁸ IAU, *IAU Strategic Plan 2020–2030*, p. 26; Worldometers, 'Countries in the world', <https://www.worldometers.info/geography/how-many-countries-are-there-in-the-world/> [accessed March 25, 2021].

⁷⁹ IAU, *IAU Strategic Plan 2020–2030*, p. 26.

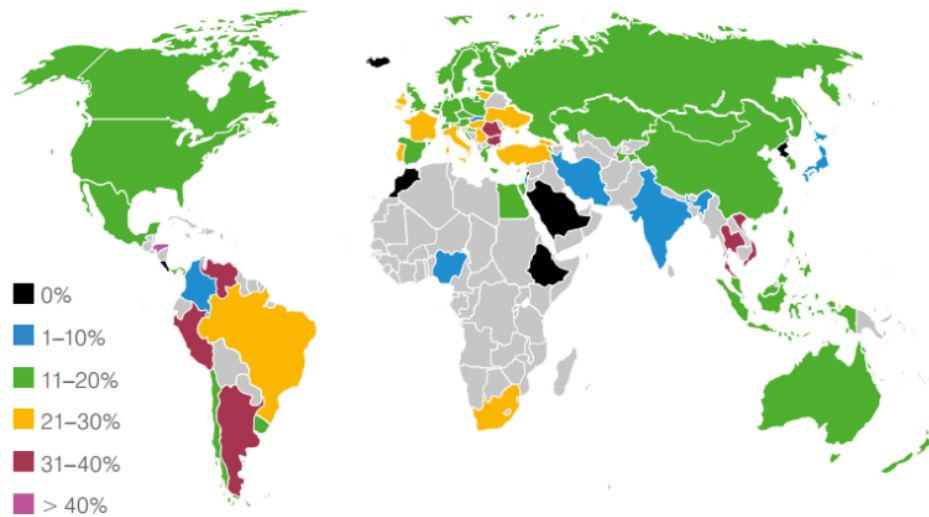


Figure 2: IAU membership by gender and geography. The colour coding indicates the percentages of female IAU members. (Source: *IAU Strategic Plan 2020–2030*, p. 26 (CC BY 4.0))

Among the IAU’s aims is to ensure ‘a younger, more diverse and inclusive astronomical community’ and, in its previous strategic plan (2010–2020), it urged for astronomy to be included in school curricula worldwide, noting that ‘while university educational programmes are highly uniform across the world, the teaching of STEM subjects in schools may vary considerably from country to country’.⁸⁰ Despite referring to this as an issue that it could not directly or centrally address, one of its commissions (C1) has overseen the development of several educational projects including the Network for Astronomy School Education, the Galileo Teacher Training Program, Universe Awareness, and the astroEDU online database of astronomy education activities.⁸¹

The publication of the IAU’s latest strategic plan preceded the 2020 opening of the IAU Office of Astronomy for Education (OAE), which is being hosted by Haus der Astronomie in Heidelberg, Germany.⁸² The OAE has within its mandate the development of standards for teaching astronomy and the provision of ‘training and resources necessary to use astronomy to stimulate teaching and education from elementary to high school level (astronomy and science education), with a network of National Astronomy

⁸⁰ IAU, *IAU Strategic Plan 2020–2030*, pp. 40, 44.

⁸¹ IAU, *IAU Strategic Plan 2020–2030*, pp. 40, 41.

⁸² Haus der Astronomie, <https://www.haus-der-astronomie.de/OAE> [accessed March 25, 2021].

Education Coordinators and a database of IAU volunteers’.⁸³ One of the OAE’s objectives is to analyse the use of astronomy in teaching in all the IAU countries and identify actions to be taken, including ‘proposing modifications to school syllabi, organising teacher training and identifying adequate teaching material that is readily accessible and can be translated into the local language’.⁸⁴ The findings of an initial analysis of the curricula of select countries conducted by Salimpour, et al. were published in a 2020 paper titled ‘The Gateway Science’, which is reviewed in the following section.⁸⁵

3.4.1 Astronomy as the ‘gateway science’?

Salimpour, et al.’s investigation of the presence and extent to which astronomy has been incorporated into 37 OECD member countries’ school curricula, and two non-OECD countries (China and South Africa), revealed that, of the 52 curricula assessed, ‘astronomy and its related topics are prevalent in at least one grade in all curricula’.⁸⁶ They reported that 40 curricula (76.9%) introduced astronomy content in Grade 1, but only 14 curricula (27%) included astronomy-related topics across all grades (Grades 1–12).⁸⁷ Grade 6 was the year of schooling in which most astronomical ideas were covered.⁸⁸ However, the choice of topics for the text-based analysis were confined to those the researchers considered ‘relevant to astronomy and its cognate fields’ and were defined as ‘those that involved scientific phenomena outside of the Earth’s atmosphere that involved the movements and phenomena seen in the night sky and the scientific theories, instrumentation, and tools that are explicitly used in astronomical research’.⁸⁹ Based on relational textual analysis, the conclusion was reached that all the major concepts fell under two broad themes (Earth and Physics), although many were incorporated into the topics Geography, Earth Science, and Nature and Environment.⁹⁰ The two broad themes comprised eight sub-themes, which appeared across all of the reviewed curricula: astronomy, Earth, energy, gravity, physics, solar system, sun, and universe.⁹¹ These were further reduced to four overlapping themes – Earth, solar system,

⁸³ IAU, *IAU Strategic Plan 2020–2030*, pp. 3, 4–5, 41.

⁸⁴ IAU, *IAU Strategic Plan 2020–2030*, p. 42.

⁸⁵ Salimpour, et al., ‘The Gateway Science’.

⁸⁶ Salimpour, et al., ‘The Gateway Science’, pp. 1, 5.

⁸⁷ Salimpour, et al., ‘The Gateway Science’, pp. 1, 5.

⁸⁸ Salimpour, et al., ‘The Gateway Science’, p. 18.

⁸⁹ Salimpour, et al., ‘The Gateway Science’, pp. 4, 6.

⁹⁰ Salimpour, et al., ‘The Gateway Science’, pp. 1, 9.

⁹¹ Salimpour, et al., ‘The Gateway Science’, pp. 9, 11, 14.

energy, and physics – indicating that most astronomy-related topics are *not* in the ‘physics’ sub-theme, which suggested that the curricula treat astronomy as distinct from physics.⁹² This appears to misalign with the statement in *Big Ideas in Astronomy* that ‘astronomy’ and ‘astrophysics’ are used interchangeably (see section 5) and, as Salimpour, et al. have suggested, may point towards a hypothesis that the curricular divergence from physics fails to address the potential of treating astronomy as the ‘gateway science’.⁹³ According to Salimpour, et al., ‘there has been no [previous] research published that focuses specifically on the position of astronomy across the international science curricula’.⁹⁴ Similarly, the claim by some educators that astronomy concepts improve learners’ interest and interaction has not received in-depth attention.⁹⁵ Despite this, and on the basis of apparently anecdotal evidence, the astronomy education research community maintains a consensus view that astronomy is a ‘gateway science’.⁹⁶

Salimpour, et al.’s research indicated that curiosity about astronomy is ignited in the early years of schooling, which is in line with previous research on initial interest in science.⁹⁷ However, they also suggested the need to re-imagine science education to keep young learners engaged.⁹⁸ Soler and Leite proposed that the main arguments for teaching astronomy were: awakening of feelings and concerns; socio-historical-cultural relevance; expansion of world view and awareness; and interdisciplinarity.⁹⁹ Additionally, Salimpour, et al. reported that ‘there is hardly any focus on indigenous astronomy or the role of prominent women astronomers’, yet the context of their research was limited to reviewing the curricula of OECD member countries, which they claimed ‘provided

⁹² Salimpour, et al., ‘The Gateway Science’, p. 12.

⁹³ Retrê, et al., *Big Ideas in Astronomy*, p. 33; Salimpour, et al., ‘The Gateway Science’, p. 13.

⁹⁴ Salimpour, et al., ‘The Gateway Science’, p. 2.

⁹⁵ Salimpour, et al., ‘The Gateway Science’, p. 15.

⁹⁶ National Research Council, ‘The role of astronomy education’, in *Astronomy and Astrophysics in the New Millennium* (Washington DC: The National Academies Press, 2001), pp. 159-176; National Research Council, *New Worlds, New Horizons in Astronomy and Astrophysics* (Washington DC: The National Academies Press, 2010); Salimpour, et al., ‘The Gateway Science’, p. 1.

⁹⁷ Salimpour, et al., ‘The Gateway Science’, p. 16; Adam V. Maltese and Robert H. Tai, ‘Eyeballs in the Fridge: Sources of early interest in science’, *International Journal of Science Education*, 32:5 (2010), pp. 669-685; Lisa Dang and Pedro Russo, ‘How astronomers view education and public outreach: An exploratory study’, *Communicating Astronomy with the Public Journal*, 18 (2015), pp. 16-22.

⁹⁸ Salimpour, et al., ‘The Gateway Science’, pp. 16, 19.

⁹⁹ D.R. Soler and C. Leite, ‘Importance and justification for teaching astronomy: A look at the area’s research’, *II National Symposium on Astronomy Education – II SNEA 2012*, São Paulo, SP, pp. 370-379, cited in José Isnaldo de Lima Barbosa and Marcos Rincon Voelzke, ‘Justifications for the teaching of astronomy in basic education: The opinion of licensed teachers in physics’, *Journal of Modern Education Review*, 8:8 (2018), p. 584.

enough diversity around the developed world'.¹⁰⁰ This suggests that research based on the curricula of developing countries may produce a different set of results. Indigenous astronomy was stated to only be present in the curricula of three countries (Canada, New Zealand and Norway), or possibly introduced at the teacher's discretion, but this assertion could be challenged as the South African school curriculum, for example, prescribes indigenous knowledge inclusion, allows for the development of localised content, and accommodates different ways of learning.¹⁰¹ Keane, however, has warned that the inclusion of indigenous knowledge 'usually consists of traditional "bits that fit" into the current syllabus', which she has argued is 'a gross oversimplification of indigenous knowledge preservation, and ... demonstrates our Western science hubris'.¹⁰²

3.4.2 Space awareness education

Universe Awareness (UNAWA) was founded in 2004 and seen as a cornerstone project of the IAU/UNESCO International Year of Astronomy in 2009.¹⁰³ The European branch, EU-UNAWA, included South Africa in recognition of the country's science and technology collaborations with the European Union.¹⁰⁴ The target age group was 4–10 year olds and, according to the project's final report, 'EU-UNAWA created a wide variety of high-quality astronomy education resources, trained hundreds of teachers and inspired thousands of young children'.¹⁰⁵ The reason for choosing astronomy as a topic was because 'it embodies a unique combination of scientific and cultural aspects'.¹⁰⁶ Despite the project's efforts to capture children's imaginations and give teachers the confidence to introduce astronomy and science topics in the classroom, it was found that learners had not necessarily been motivated to develop skills and competencies in science and technology.¹⁰⁷

¹⁰⁰ Salimpour, et al., 'The Gateway Science', pp. 1, 3.

¹⁰¹ Salimpour, et al., 'The Gateway Science', pp. 5, 13; Department of Education of South Africa, *Revised National Curriculum Statement Grade R–9* (Pretoria: Government Printers, 2002); Department of Education of South Africa, *National Curriculum Statement Grades 10–12* (Pretoria: Government Printer, 2003).

¹⁰² Keane, 'Science education and worldview', pp. 588–589.

¹⁰³ UNAWA, 'Universe Awareness', <https://www.unawe.org/about/background/> [accessed November 6, 2020].

¹⁰⁴ EU-UNAWA, 'Final Report Summary – EU-UNAWA (Building on the International Year of Astronomy: Making young children aware of the Universe)', Universiteit Leiden, Netherlands (2015), p. 3.

¹⁰⁵ EU-UNAWA, 'Final Report Summary', pp. 2, 4.

¹⁰⁶ EU-UNAWA, 'Final Report Summary', p. 3.

¹⁰⁷ EU-UNAWA, 'Final Report Summary', p. 4.

While children may be able to understand but not explain scientific ideas from an early age, it was suggested that they would ‘benefit enormously from appropriate instruction and educational activities aimed at teaching them basic facts’.¹⁰⁸ This ‘theory neutral’ position has, however, been disputed among developmental psychologists, and some researchers have noted that education programmes that are not responsive to local cultures tend to have lower enrolment and retention.¹⁰⁹ It was also noted that most teachers had no previous experience teaching astronomy-related subjects, ‘nor had they ever combined the scientific and cultural aspects of sky observation’.¹¹⁰ Although the EU-UNAWWE report claimed that culture in astronomy education was an important topic, it also indicated that resources on the connection were either difficult to find or that there were gaps in the available materials.¹¹¹ Attention was also drawn to the fact that many stories about astronomy in indigenous cultures have not yet been recorded.¹¹²

3.4.3 Culturally responsive astronomy education

In the 1980s, educational anthropology and, later, multicultural education brought focus to culture-based teaching and learning.¹¹³ More recent research by Lee on using a culturally responsive curriculum and pedagogy for an introductory college-level astronomy course in the USA highlighted some points that are also relevant to school-level astronomy education.¹¹⁴

Lee used Geneva Gay’s definition of culture to inform her research:

Culture refers to a dynamic system of social values, cognitive codes, behavioural standards, world views, and beliefs used to give order and meaning to our own lives as well as the lives of others. Even without our being consciously aware of it, culture strongly influences how we think, believe, communicate, and behave, and these, in turn affect how we teach and learn. Because teaching and learning are always mediated or shaped by cultural influences, they can never be culturally neutral.¹¹⁵

¹⁰⁸ EU-UNAWWE, ‘Final Report Summary’, p. 4.

¹⁰⁹ EU-UNAWWE, ‘Final Report Summary’, p. 6.

¹¹⁰ EU-UNAWWE, ‘Final Report Summary’, p. 16.

¹¹¹ EU-UNAWWE, ‘Final Report Summary’, p. 30.

¹¹² EU-UNAWWE, ‘Final Report Summary’, p. 30.

¹¹³ Lee, ‘The effects on student knowledge and engagement’, p. 50.

¹¹⁴ Lee, ‘The effects on student knowledge and engagement’, p. 1.

¹¹⁵ Geneva Gay, *Culturally Responsive Teaching: Theory, research, and practice* (New York: Teachers College Press, Columbia University, 2010), p. 8.

As mentioned in the review of literature on the science–culture divide (section 3.1), science is rooted in Western European culture and based on the premise of objectivity and the scientific method. However, research by Douglas Medin and Megan Bang concluded that the scientific method was ‘idealistic and overly optimistic’, and ‘embedded with values defined by culture, race, gender and socioeconomic status’.¹¹⁶ Therefore, as Lee has indicated, it is important to examine which parts of science have been shaped by colonial world views and how these could be redefined in a postmodern society and increasingly ethnically diverse classrooms.¹¹⁷

Lee’s research found a correlation between culturally responsive pedagogy and students who were not only more engaged, but also learned more science/astronomy.¹¹⁸ Similarly, underrepresented minority and female students were also positively affected through increased cultural relevancy and responsiveness.¹¹⁹ What was not clear, however, was how these findings linked to the reasons students gave for ‘migrating away from STEM’, which included ‘uninspiring introductory courses, difficulty in math, and an unwelcoming academic culture in STEM’.¹²⁰

According to Lee, the cross-discipline of astronomy, anthropology and archaeology offers opportunities to ‘build common ground between academia and indigenous communities’.¹²¹ This suggests that the discipline of cultural astronomy may have an important role to play at multiple levels of the science–culture interface. Literature about this will be considered in the following section.

¹¹⁶ Douglas L. Medin and Megan Bang, *Who’s Asking?: Native Science, Western Science, and Science Education* (Cambridge, MA: The MIT Press, 2014), cited in Lee, ‘The effects on student knowledge and engagement’, p. 24.

¹¹⁷ Lee, ‘The effects on student knowledge and engagement’, p. 24.

¹¹⁸ Lee, ‘The effects on student knowledge and engagement’, pp. 79, 80.

¹¹⁹ Lee, ‘The effects on student knowledge and engagement’, pp. 81, 82, 83.

¹²⁰ PCAST, ‘Engage to Excel: Producing one million additional college graduates with degrees in Science, Technology, Engineering, and Mathematics’, Department of Education Institute of Education Statistics, Washington, DC: Executive Office of the President (2012), cited in Lee, ‘The effects on student knowledge and engagement’, p. 2.

¹²¹ Lee, ‘The effects on student knowledge and engagement’, p. 17.

3.5 Cultural astronomy at the science–culture interface

Whereas Jarita Holbrook has referenced cultural astronomy as simply ‘the study of humans and their relationship to the sky’, Nicholas Campion has offered an expanded description:

The use of astronomical knowledge, beliefs or theories to inspire, inform or influence social forms and ideologies, or any aspect of human behaviour. Cultural astronomy also includes the modern disciplines of ethnoastronomy and archaeoastronomy.¹²²

Ethnography is considered the ‘hallmark of cultural anthropology’, aiming to understand the world from the insider or emic perspective.¹²³ Inherent in this approach are theories of culture, such as Clifford Geertz’s interpretive theory of culture, which emphasises the consideration of local frameworks – not universal laws – in understanding culture, and Herbert Blumer’s theory of symbolic interactionism, wherein culture comprises interactions and behaviours that have meaning within a particular context.¹²⁴ As Ruggles has pointed out, while it is ‘tempting to see the immutable cycles of the sky as a passive backdrop’ (from a Western perspective), ‘the practice of astronomy is a central part of socio-cultural experience for non-Western peoples’.¹²⁵ Studies of African cultural astronomy, for example, have raised awareness of the significant relationships African peoples had, and in some instances still have, with the sky in terms of timekeeping, establishing calendars, navigation, fertility cycles, agriculture, medicine, art and ceremony.¹²⁶ Cheryl Bartlett, et al. have also pointed out that indigenous knowledge is not a book-based learning process, but rather transferred through ‘stories, songs, crafts, practices, family, community, language, ceremonies, and connectivity with the land’.¹²⁷

¹²² Jarita Holbrook, ‘Astronomy, indigenous knowledge and interpretation: Advancing studies of Cultural Astronomy in South Africa’, *Journal of Astronomy in Culture*, 1:1 (2016), p. 1; Nicholas Campion, ‘Editorial’, *Culture and Cosmos*, 1:1 (1997), p. 2.

¹²³ Monique Hennink, Inge Hutter, and Ajay Bailey, *Qualitative Research Methods* (London: SAGE Publications, 2011), p. 15.

¹²⁴ Clifford Geertz, *The Interpretation of Cultures* (New York: Basic Books, 2017); Herbert Blumer, *Symbolic Interactionism: Perspective and method* (California: California University Press, 1986).

¹²⁵ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 8.

¹²⁶ Johnson O. Urama and Jarita C. Holbrook, ‘The African Cultural Astronomy Project’, *Proceedings of the International Astronomical Union* 5(S260) (2009), pp. 48-53; Lee, ‘The effects on student knowledge and engagement’, p. 17.

¹²⁷ Cheryl Bartlett, Murdena Marshall and Albert Marshall, ‘Two-Eyed Seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing’, *Journal of Environmental Studies and Sciences*, 2 (2012), p. 337.

Currently, the Master's programme in Cultural Astronomy and Astrology offered by the University of Wales Trinity Saint David is the only academic degree to examine people's relationship with the cosmos, albeit from a predominantly Western cultural perspective.¹²⁸ It draws on different disciplines from the humanities, including history, anthropology, archaeology, sociology, philosophy and the study of religions, to offer as full a view as possible of the subject.¹²⁹ Referring to cultural astronomy as a subfield of anthropology, however, Ruggles has suggested that the discipline may appeal to specialist ethnoastronomers and archaeoastronomers by offering 'a better understanding of non-Western concepts and practices that ... are, in the broadest sense, "scientific"'.¹³⁰ Whereas Ruggles has insisted that ethnoastronomers 'need to move on from Western description and analysis of non-Western concepts', the UNESCO Portal to the Heritage of Astronomy states that 'all cultural uses of astronomy are indigenous', which appears to introduce another dichotomy as this has been assumed 'to apply only to people outside the "Western" framework of thought, given the global nature of modern science'.¹³¹ The portal offers the following description of indigenous astronomy:

Indigenous astronomy concepts include a range of ideas, beliefs, and understandings connected to the sky that may not be attached to a physical site. These include weather prediction; celestial deities such as solar, lunar, and stellar gods and goddesses; and 'sun kings' as an example of rulers who attribute the right to rule to a direct connection to a celestial body. Cosmological concepts may also be made real in physical structures such as the planning of cities and tombs.¹³²

According to Steven Gullberg, while ethnoastronomy deals with the astronomical systems of indigenous peoples (combining anthropology and astrology, and sometimes incorporating data drawn from prehistory, geology, linguistics and genetics), archaeoastronomy deals with the astronomical significance of sites and structures of prehistoric peoples, and is interdisciplinary in that it incorporates astronomy, archaeology and anthropology.¹³³ Archaeoastronomy is a relatively recent discipline that emerged in

¹²⁸ UWTSd, 'Cultural Astronomy and Astrology (MA)', <https://www.uwtsd.ac.uk/ma-cultural-astronomy-astrology/> [accessed March 25, 2021]

¹²⁹ UWTSd, 'Cultural Astronomy and Astrology (MA)'.

¹³⁰ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy', p. 8.

¹³¹ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy', p. 11; UNESCO Portal to the Heritage of Astronomy, 'Theme: Indigenous uses of Astronomy', <https://www3.astronomicalheritage.net/index.php/show-theme?idtheme=9> [accessed March 25, 2021].

¹³² UNESCO Portal to the Heritage of Astronomy, 'Theme: Indigenous uses of Astronomy'.

¹³³ Steven R. Gullberg, 'Cultural astronomy and educational opportunities', *Astronomical Notes*, 340:9-10 (2019), p. 810.

the 1960s/1970s and, as Gullberg has stated, ‘the field has now evolved to the point where dedicated educational programs are essential. As in any field, proper education is the key to the future.’¹³⁴ While he offered no explanation of what ‘proper education’ might be, he does make specific reference to ‘science-oriented’ archaeoastronomy.¹³⁵

Championing astronomical heritage, Ruggles has drawn attention to the insights that may be gained from ancient and more recent indigenous cosmologies by studying the layout and alignments of astronomically significant sites.¹³⁶ It is tangible *and* intangible heritage, he claims, that help to ‘reinforce modern cultural identities and esteem’, before adding that demonstrating the ways different communities have understood and interpreted the sky will ‘generate enthusiasm and support for progress in modern astronomy’.¹³⁷

Gullberg has claimed that the IAU is now the focal point for collaborative efforts in archaeoastronomy and astronomy in culture, and that it plays a worldwide central role in guiding further development and education in this field, seen as integral to the history of astronomy.¹³⁸ However, he then offers a somewhat limited view that ‘Astronomy in culture helps to provide historical and cultural insight to those working in other areas of astronomy’ and that people study archaeoastronomy out of curiosity and to increase their knowledge.¹³⁹

3.5.1 Astrology

Based on the Western perception that astrology lacked scientific validity, *astrologia* (the interchangeable term for astronomy and astrology) was separated into two disciplines in the seventeenth century, despite both relying on the same raw data: sky, stars, planets, and the cosmos. As British philosopher Janet Radcliffe Richards noted, ‘astrology had been a respectable (though not very successful) science for most of the history of astronomy, and most astronomers had also been astrologers; in fact, belief in astrology had provided much of the original motivation for the study of astronomy’.¹⁴⁰ While Champion has stated that astrology is a universal feature of human society and needs to be

¹³⁴ Gullberg, ‘Cultural astronomy and educational opportunities’, p. 816.

¹³⁵ Gullberg, ‘Cultural astronomy and educational opportunities’, p. 816.

¹³⁶ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 14.

¹³⁷ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 14.

¹³⁸ Gullberg, ‘Cultural astronomy and educational opportunities’, p. 811.

¹³⁹ Gullberg, ‘Cultural astronomy and educational opportunities’, pp. 811, 812.

¹⁴⁰ Janet Radcliffe Richards, *Human Nature After Darwin* (Milton Keynes: The Open University, 1999), p. 23.

studied as a form of cultural astronomy, a general view held by those involved in science is that the persistence of astrology in Western culture indicates that it is 'apparently immune to extinction despite scientific advance and education'.¹⁴¹

According to Ruggles, astrology is denounced by modern astronomers on the basis that any connection between celestial bodies and current or future terrestrial events rebuts the laws of physics.¹⁴² However, it is open to debate whether the distinctions of measurement and meaning are mutually exclusive among many non-Western cultures that hold beliefs around the fundamental interconnectedness of the sky and earth (which could be termed astrological) extending back into prehistory.¹⁴³ A question raised by Ruggles and Hoskin is whether culture can be understood separately to the sky. As they pointed out, the sky was a cultural resource 'long before the invention of writing or the construction of observing instruments'.¹⁴⁴

Given the resistance of most Western astronomers to astrology, Ruggles queried whether astrologers can be taken seriously as modern academics.¹⁴⁵ However, Campion pointed out that astrology may be understood as a form of ethnoastronomy and overlaps with archaeoastronomy, and that 'a Western astronomer who may be ... contemptuous of Western astrology would probably not dare express the same sentiments regarding, say, Native American cosmology or sub-Saharan celestial divination'.¹⁴⁶ Ruggles, however, highlighted a distinction between 'genuine cultural world-views' and 'new age belief systems' – the former, he suggested, not having access to modern scientific evidence and using a logic different from Western logic, while the latter is acquainted with but chooses to challenge and dismiss it.¹⁴⁷

¹⁴¹ Nicholas Campion, 'Astrology as Cultural Astronomy', in *Handbook of Archaeoastronomy and Ethnoastronomy*, ed. by Clive L.N. Ruggles (Springer: New York, 2015), p. 114; Martin Ince, *Dictionary of Astronomy* (London: Fitzroy Dearborn Publishers, 1997), p. 12; European Commission, 'Special Eurobarometer 224: Europeans, Science and Technology' (2005), pp. 35, 37, https://ec.europa.eu/comfrontoffice/publicopinion/archives/ebs/ebs_224_report_en.pdf [accessed March 25, 2021].

¹⁴² Clive Ruggles, *Ancient Astronomy: An Encyclopaedia of Cosmologies and Myth* (Santa Barbara, CA: ABC-CLIO, 2005), p. 4.

¹⁴³ Ruggles, *Ancient Astronomy*, p. 27.

¹⁴⁴ Clive Ruggles and Michael Hoskin, 'Astronomy before History', in *The Cambridge Concise History of Astronomy*, ed. by Michael Hoskin (Cambridge: Cambridge University Press, 2008), p. 1.

¹⁴⁵ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy', p. 10.

¹⁴⁶ Campion, 'Astrology as Cultural Astronomy', pp. 103, 105; Nicholas Campion, 'Teaching Cultural Astronomy: On the development and evolution of the syllabus at Bath Spa University and the University of Wales, Lampeter', in *African Cultural Astronomy: Current archaeoastronomy and ethnoastronomy research in Africa*, ed. by Jarita Holbrook, Rodney Medupe and Johnson Urama (Dordrecht: Springer Science+Business Media BV, 2008), p. 116.

¹⁴⁷ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy', p. 11.

3.6 Locating indigenous knowledge

According to El-Hani and Bandeira, any discussion about multicultural science education requires consideration of the relationships between modern Western science and indigenous knowledge, with its related epistemological concerns and sociocultural issues.¹⁴⁸ However, they warned that broadening the concept of science to include ‘ethnoscience’ would not help to acknowledge the legitimacy and validity of other ways of knowing.¹⁴⁹ They cautioned that this could reinforce the ‘revered place’ of science and may lead to judging other ideas by the standards and values used by the scientific community.¹⁵⁰ However, Kai Horsthemke has questioned whether the ideas of indigenous knowledge, science, and technology make any sense, citing a lack of clarity around the meaning of ‘knowledge’.¹⁵¹ Fulvio Mazzocchi also picked up on this aspect and suggested that ‘our difficulty in approaching the knowledge from indigenous cultures is already reflected in the way in which we describe and name it’.¹⁵² He noted that there is no universal definition for the many terms used to indicate what people know, each of which carries what he refers to as ‘different implications’.¹⁵³ For example:

... ‘traditional’ places the emphasis on the transmission of knowledge along a cultural continuity, but might ignore the ability of traditional societies to adapt to changing circumstances. Another widely used word, ‘indigenous’, is meant to highlight the autochthonous nature of this knowledge, but it might overlook knowledge from populations who are not officially recognised as indigenous. The word ‘local’ can be applied to different geographic contexts, but it lacks specificity.¹⁵⁴

Bartlett, et al. have suggested that traditional knowledge is a mirror image of one’s spirituality and that, while science explains many things, the spiritual realm can also be drawn on for this.¹⁵⁵ They considered indigenous knowledge a living knowledge that is not static and of the past, but acquired over a person’s life journey, part of the present,

¹⁴⁸ El-Hani and Bandeira, ‘Valuing indigenous knowledge’, p. 752.

¹⁴⁹ El-Hani and Bandeira, ‘Valuing indigenous knowledge’, p. 752.

¹⁵⁰ El-Hani and Bandeira, ‘Valuing indigenous knowledge’, p. 753.

¹⁵¹ Kai Horsthemke, ‘Indigenous (African) Knowledge Systems, Science, and Technology’, in *The Palgrave Handbook of African Philosophy*, ed. by Adeshina Afolayan and Toyin Falola (London: Palgrave Macmillan, 2017), p. 585.

¹⁵² Fulvio Mazzocchi, ‘Western science and traditional knowledge’, *EMBO Reports*, 7:5 (2006), p. 463.

¹⁵³ Mazzocchi, ‘Western science and traditional knowledge’, p. 463.

¹⁵⁴ Mazzocchi, ‘Western science and traditional knowledge’, p. 463.

¹⁵⁵ Bartlett, et al., ‘Two-Eyed Seeing’, p. 332.

and meaningful in their lives and communities.¹⁵⁶ This concurs with Ruggles' comments on indigenous world views being dynamic and adaptive to new experiences, and Anthony Aveni's observation that 'the practice of observing and making sense of celestial phenomena is as much a cultural activity as any other, and consequently it is equally sensitive to the varied processes of cultural change'.¹⁵⁷

Keane has proposed designing curricula that integrate cultural practices as performative and factual knowledge, and consider sociocultural influences as a resource.¹⁵⁸ This would require a community-centred approach rather than a learner-centred approach, which Keane has suggested could largely resolve 'tensions between an African world view and a scientific world view', and would align with Jarita Holbrook's indication of astronomical knowledge being interwoven with culture in Africa.¹⁵⁹ Additionally, Ruggles has indicated that indigenous and cultural astronomy are gaining momentum and recognition as interdisciplinary academic disciplines, evidenced through projects such as the African Cultural Astronomy Project.¹⁶⁰ With some 80% of the world's societies having a collective culture, this appears to point to a need for what Jegede terms 'collateral learning', rather than the further subjugation of cultural knowledge to a dominant Western paradigm.¹⁶¹ This may be best summed up in 'Two-Eyed Seeing', which was acknowledged as part of the International Year of Astronomy's celebrations in 2009, but which Bartlett, et al. claimed is difficult to convey to academics as 'it does not fit into an particular subject area or discipline':¹⁶²

Two-Eyed Seeing is learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of Western knowledges and ways of knowing, and to use both these eyes for the benefit of all.¹⁶³

¹⁵⁶ Bartlett, et al., 'Two-Eyed Seeing', pp. 335-336, 337.

¹⁵⁷ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy', p. 9; Anthony Aveni, *Foundations of New World Cultural Astronomy* (Colorado: University Press of Colorado, 2008), pp. 726-727.

¹⁵⁸ Keane, 'Science education and worldview', p. 610.

¹⁵⁹ Keane, 'Science education and worldview', p. 610; J.C. Holbrook, 'African Cultural Astronomy – Current Activities', *African Skies/Cieux Africains*, 11 (2007), p. 24.

¹⁶⁰ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy'; Urama and Holbrook, 'The African Cultural Astronomy Project'.

¹⁶¹ Olugbemiro J. Jegede, 'Collateral Learning and the Eco-Cultural Paradigm in Science and Mathematics Education in Africa', *Studies in Science Education*, 25:1 (1995), pp. 97-137.

¹⁶² Bartlett, et al., 'Two-Eyed Seeing', pp. 336, 338.

¹⁶³ Bartlett, et al., 'Two-Eyed Seeing', pp. 336.

While this would support emerging theory for transdisciplinary research, such curricular intertwining of world-views would need to acknowledge that current mainstream knowledges and educational approaches have developed out of the efforts to remove spirituality and religion from curricula.¹⁶⁴ As such, Bartlett, et al. recognised that Two-Eyed Seeing would require decolonising work, or increased exposure, irrespective of the cultural background.¹⁶⁵ El-Hani and Bandeira have also indicated that the connection between science and epistemic superiority requires disentangling.¹⁶⁶

Some researchers suggest that it is better to use ‘science’ to refer to the way of knowing typical of modern Western societies and separate from other ways of knowing that have been ‘built and legitimized in distinct sociocultural circumstances’.¹⁶⁷ A point of contention, however, is that science has often been ‘used to dominate the public square as if all other discourses were of lesser value’.¹⁶⁸ Ruggles has also commented, from an anthropological perspective, that ‘a “path of progress” in astronomical discovery is anathema, since it implicitly downgrades other cultural perspectives’.¹⁶⁹ However, El-Hani and Bandeira have claimed indigenous knowledge cannot be deemed inferior because it does not generalise observations to universal laws, build models based on the abstract, or quest for the same kind of predictive power as science.¹⁷⁰

4. The universal sky / diverse cultures dichotomy

A comment made by one of Buxner and Holbrook’s research respondents that ‘one way to destroy local culture was to talk about the universality of the sky ... and that this way of thinking would destroy cultural diversity’, prompted my investigation of a potential universal sky / diverse cultures dichotomy.¹⁷¹ A similar disparity exists between positivist and interpretive paradigms. The interpretive paradigm is commonly described as having

¹⁶⁴ Bartlett, et al., ‘Two-Eyed Seeing’, pp. 331, 332.

¹⁶⁵ Bartlett, et al., ‘Two-Eyed Seeing’.

¹⁶⁶ El-Hani and Bandeira, ‘Valuing indigenous knowledge’, p. 755.

¹⁶⁷ William W. Cobern and Cathleen C. Loving, ‘Defining “science” in a multicultural world: Implications for science education’, *Science Education*, 85:1 (2001), pp. 50-67, cited in El-Hani and Bandeira, ‘Valuing indigenous knowledge’, p. 754.

¹⁶⁸ Cobern and Loving, ‘Defining “science” in a multicultural world’, p. 62.

¹⁶⁹ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 1.

¹⁷⁰ El-Hani and Bandeira, ‘Valuing indigenous knowledge’, p. 758.

¹⁷¹ Buxner and Holbrook, ‘Integrating African Cultural Astronomy into the Classroom’, pp. 88-89.

emerged during the 1970s in response to the shortcomings of positivism, which was seen as the foundation of objective, statistic-based, value-free science that circumvented any acknowledgement of contextual influences on people's lives.¹⁷² In contrast, the interpretive paradigm recognises that 'reality is socially constructed as people's experiences occur within social, cultural, historical or personal contexts'.¹⁷³

4.1 Universality

Ruggles, and others, have posited that there is an assumption around the universe existing as an objective reality, subject to universally applicable physical laws and in which individuals are passive observers.¹⁷⁴ Anthropology indicates that this is not a view that is shared the world over. Instead, Ruggles has argued, indigenous peoples 'establish interconnections and create cultural taxonomies on the basis of social agreement and using "dialectic" rather than "rationalistic" logic', Cartesian dualities or Linnaean categories'.¹⁷⁵ The framework of alternative rationality suggests that indigenous cosmologies represent 'science' in its broadest sense, which is consistent with UNESCO's statement that 'in a global context, "science" may be defined broadly as "knowledge or systems of knowledge, including traditional knowledge"'.¹⁷⁶ This also aligns with El-Hani and Bandeira's acceptance of the presence of objectivity and universality in Western science and elsewhere if these terms are reinterpreted and detached from scientism (the ideology that asserts the superiority of modern science).¹⁷⁷

Based on the assumption that any body of knowledge is socially constructed, El-Hani and Bandeira suggested that science as way of knowing could be considered 'local' because: it is a product of particular sociocultural and historical circumstances in Western Europe and universal from not only an epistemological, but also a sociological perspective; the scientific endeavour is transnational and cross-cultural; scientists around the world display similar attitudes, values, practices and knowledge; and no scientist can be free from the influence of the culture in which they were born.¹⁷⁸ In the same vein, Campion

¹⁷² Hennink, Hutter and Bailey, *Qualitative Research Methods*, p. 12.

¹⁷³ Hennink, Hutter and Bailey, *Qualitative Research Methods*, p. 15.

¹⁷⁴ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy', p. 6; Brayboy and Castagno, 'How might native science inform "informal science learning"?'.

¹⁷⁵ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy', p. 7.

¹⁷⁶ Ruggles, 'Indigenous Astronomies and Progress in Modern Astronomy', p. 7.

¹⁷⁷ El-Hani and Bandeira, 'Valuing indigenous knowledge', p. 758.

¹⁷⁸ El-Hani and Bandeira, 'Valuing indigenous knowledge', p. 759.

points out that ‘the scholar can no longer pretend that their own conditioning, bias and unconscious responses, have no impact on their enquiry’.¹⁷⁹

As Ann Ryan has indicated, holding Western science as rational universal truth has ‘narrowed and fragmented Western perceptions of the world’, and effectively suppressed the idea that that meaning can be found in social and cultural experiences.¹⁸⁰ With this in mind, science-focused astronomy theoretically could be considered a branch of cultural astronomy, and a case could be made for astrology as an indigenous astronomy.¹⁸¹

4.2 Destroying cultural diversity?

Looking at indigenous astronomies alongside modern science may, as Ruggles has suggested, strengthen cultural identities and facilitate scientific progress simultaneously.¹⁸² However, the distinction between ‘genuine’ indigenous cosmologies and ‘alternative’ (Western) world views suggests this will be an area of ongoing debate.¹⁸³ While some researchers may be concerned that introducing modern science in indigenous contexts will distort or destroy indigenous knowledge systems and have a negative effect on cultural diversity, there is also a need to recognise that indigenous world-views are dynamic and adapt in the context of new evidence.¹⁸⁴ Ruggles has called for sensitivity to the perception of the Western world as ‘patronising, detrimental, and even colonial’ and the notion of the scientific viewpoint as superior instead of ‘just different’, as this could not only be interpreted as counterproductive, but also offensive, even when there is a genuine intention to share knowledge and enthusiasm about the universe, and encourage active engagement.¹⁸⁵ That said, and as El-Hani and Bandeira have observed, many learners will likely need to move between their own culture and mainstream Western culture, which is highly influenced by science and technology.¹⁸⁶ It is inevitable, therefore, that any indigenous culture will change through exposure to science education, and it is only if cultural erosion takes place that this becomes problematic.¹⁸⁷ Whereas

¹⁷⁹ Campion, ‘Teaching Cultural Astronomy’, p. 115.

¹⁸⁰ Ann Ryan, ‘Indigenous knowledge in the science curriculum: Avoiding neo-colonialism’, *Cultural Studies of Science Education*, 3 (2008), p. 700.

¹⁸¹ Radcliffe Richards, pp. 69, 86.

¹⁸² Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 15.

¹⁸³ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 15.

¹⁸⁴ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 15.

¹⁸⁵ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 15.

¹⁸⁶ El-Hani and Bandeira, ‘Valuing indigenous knowledge’, p. 771.

¹⁸⁷ El-Hani and Bandeira, ‘Valuing indigenous knowledge’, p. 771.

being aware of the possibilities and limits of science and creating space for other ways of knowing would enable learners to dialogue with their own perspectives, different ways of knowing have different epistemological, methodological and ontological foundations.¹⁸⁸ This would require teachers to adopt a multidisciplinary approach and have specific knowledge sets, which may not be available through current teacher training programmes.

Valuing and recording indigenous knowledge is also a heritage issue – not, as Ruggles has suggested, in the sense that this knowledge should be ‘frozen’, but rather that it should not prevent a flow of new ideas into indigenous knowledge systems.¹⁸⁹ His summation was that while mutual contact and education was helpful, reconciliation could only be achieved through fundamental attempts by astronomers to understand and respect the non-Western frameworks of thought that gave rise to other cultural perspectives and their associated heritage.¹⁹⁰

Returning to Buxner and Holbrook’s respondent’s concerns about universal thinking destroying cultural diversity raises the possibility that their view may have been based in a perception of astronomy and science as embedded in negative colonial and superiority dimensions. That Buxner and Holbrook referred to cultural astronomy as ‘the science that looks at [the] relationship between astronomy and culture’ may also have influenced the respondent’s comments.¹⁹¹ From a theoretical perspective, it is evident that more attention is being paid to indigenous and cultural viewpoints, and that cultural identity and scientific progress are not mutually exclusive. However, there are indications that this may not yet be fully embraced in the current iteration of *Big Ideas in Astronomy*, which is discussed in the following section.

¹⁸⁸ El-Hani and Bandeira, ‘Valuing indigenous knowledge’, pp. 769-770.

¹⁸⁹ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 15.

¹⁹⁰ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 15.

¹⁹¹ Buxner and Holbrook, ‘Integrating African Cultural Astronomy into the Classroom’, p. 83.

5. Big Ideas in Astronomy

‘What should science-educated citizens know about astronomy?’¹⁹² This is the question explored by João Retrê, et al. in *Big Ideas in Astronomy*, which has been developed as a roadmap for educators and astronomers in achieving astronomy literacy goals, and is said to expand on similar work done by other scientific disciplines and projects.¹⁹³ Astronomy is defined here as ‘the science that studies the origin and evolution of the Universe and everything in it’, although there is the acknowledgement that astronomy is ‘part of humanity’s cultural and scientific history’.¹⁹⁴ The 11 Big Ideas in Astronomy are:¹⁹⁵

1. Astronomy is one of the oldest sciences in human history
2. Astronomical phenomenon can be experienced in our daily lives
3. The night sky is rich and dynamic
4. Astronomy is a science that studies celestial objects and phenomena in the Universe
5. Astronomy benefits from and stimulates technology development
6. Cosmology is the science of exploring the Universe as a whole
7. We all live on a small planet within the Solar System
8. We are all made of stardust
9. There are hundreds of billions of galaxies in the Universe
10. We may not be alone in the Universe
11. We must preserve Earth, our only home in the Universe.

More detail on the main ideas and their subsets appears in Appendix II.

In the context of the examined literature (section 3), what follows is an overview of the Big Ideas’ content that is relevant to cultural and indigenous astronomies.

That astronomy is one of the oldest sciences in human history (Big Idea 1) is not disputed. A specific point, however, is made about astronomy being different to astrology by way of its [astronomy’s] use of the ‘scientific method’, although it is noted that, until pre-modern times, the distinction was vague.¹⁹⁶ However, it is explicitly stated that ‘astronomy is a science and astrology is not’, with astrology being defined as ‘[using]

¹⁹² Retrê, et al., *Big Ideas in Astronomy*, p. 8.

¹⁹³ Retrê, et al., *Big Ideas in Astronomy*, p. 8.

¹⁹⁴ Retrê, et al., *Big Ideas in Astronomy*, p. 10.

¹⁹⁵ Retrê, et al., *Big Ideas in Astronomy*, pp. 6-7.

¹⁹⁶ Retrê, et al., *Big Ideas in Astronomy*, p. 20.

positions of celestial objects to predict future events', alongside the claim that 'extensive studies' show it to be inaccurate and without any scientific foundation.¹⁹⁷ This appears to bear out Ruggles' discussion of astrology as anathema to modern astronomers, as well as expressing a positivist approach, suggesting that 'non-science' discourses are of less value and rejecting that the sky can have a contextual influence on peoples' lives.¹⁹⁸

Big Idea 2: 'Astronomical phenomena can be experienced in our daily lives' is outlined only according to the topics of day/night, seasons, moon phases, eclipses, tides, auroras, and technology.¹⁹⁹ Similarly, Big Idea 3: 'The night sky is rich and dynamic' is only considered from the perspective of naked-eye observation and navigation, and declines to acknowledge any ways of knowing other than the scientific.²⁰⁰ The trend continues with Big Idea 4: 'Astronomy is a science that studies celestial objects and phenomena in the Universe', with no reference to cultural and/or indigenous astronomies which study the same objects and phenomena.²⁰¹ The scientific stance is further reinforced by stating that 'astronomical research combines knowledge from different fields, such as physics, mathematics, chemistry and biology' (Big Idea 4.5), and that it is 'divided into a number of specialities' (Big Idea 4.6), which include 'astrobiology, cosmology, observational astronomy, astrochemistry and planetary science'.²⁰² While this appears to indicate that cross-science co-operation is encouraged, no reference is made to the humanities or the arts (a component of STEAM curricula), and could be interpreted as perpetuating a science-culture divide.²⁰³ In addition, Salimpour, et al.'s comment that 'Astronomy and Physics are often seen as different domains [in curricula], with astronomy content being more facts based, than based on concepts' appears to be at odds with the statement made in *Big Ideas in Astronomy* that, 'Given the important role that physics plays within astronomy, the terms "astrophysics" and "astronomy" are used interchangeably'.²⁰⁴ That 'astrophysics' and 'cultural astronomy' are not interchangeable suggests that there is preferential profiling of science-based specialisation, which Snow and others have discussed as problematic.²⁰⁵ The claim of Big Idea 6: 'Cosmology is the science of

¹⁹⁷ Retrê, et al., *Big Ideas in Astronomy*, p. 20.

¹⁹⁸ Ruggles, *Ancient Astronomy*, p. 4.

¹⁹⁹ Retrê, et al., *Big Ideas in Astronomy*, pp. 22-25.

²⁰⁰ Retrê, et al., *Big Ideas in Astronomy*, pp. 26-29.

²⁰¹ Retrê, et al., *Big Ideas in Astronomy*, pp. 30-33.

²⁰² Retrê, et al., *Big Ideas in Astronomy*, p. 33.

²⁰³ Retrê, et al., *Big Ideas in Astronomy*, p. 20.

²⁰⁴ Retrê, et al., *Big Ideas in Astronomy*, p. 33; Salimpour, et al., 'The Gateway Science', p. 1.

²⁰⁵ Snow, *The Two Cultures*, p. 18; Wertheim, *Pythagoras' Trousers*, p. 12.

exploring the Universe as a whole’ is also problematic in that traditional/anthropological conceptions of cosmology, as outlined by Campion, which deal with the ways in which people relate to the cosmos, are not considered.²⁰⁶

The final Big Idea (Big Idea 11: ‘We must preserve Earth, our only home in the Universe’) has a particular environmental focus, referring to, for example, light pollution and human-made space-tech debris.²⁰⁷ Specifically, it refers to humans having a significant impact on Earth’s environment (Big Idea 11.4), and that industrial society, while offering numerous advantages, has created several environmental problems on Earth; that the climate and the atmosphere are heavily affected by human activity (Big Idea 11.5); and that ‘astronomy provides us with a unique cosmological perspective that reinforces our unity as citizens of the Earth’ (Big Idea 11.7).²⁰⁸ All of these factors have direct cultural and environmental links and impacts, and yet any mention of cultural astronomy and, more so, indigenous knowledge as environmental knowledge has been omitted.

Despite the IAU’s Strategic Plan 2020–2030 including ‘Culture and Society’ as a category to illustrate astronomy’s connection with other disciplines (Figure 1, p. 20), a word search of *Big Ideas in Astronomy* produced the results shown in Table 2. Notably, ‘cosmology’ is only referred to as ‘the science of exploring the universe as a whole’, as a ‘speciality’, and as ‘a research field which studies the evolution and structure of the universe’.²⁰⁹

Table 2: Instances of words searched in *Big Ideas in Astronomy*.²¹⁰

Words searched	Instances	Big Idea no.
Culture/cultural	1	1.2
Tradition/traditional	0	n/a
Indigenous	2	1.2
Myth	2	1.1, 1.2
Cosmology	2	4.6, 6.1

²⁰⁶ Retrê, et al., *Big Ideas in Astronomy*, pp. 38-42; Campion, Nicholas, ‘The Importance of Cosmology in Culture: Contexts and Consequences’, in *Trends in Modern Cosmology*, ed. by Abraao Jesse Capistrano de Souza (InTech Open, 2017), <https://www.intechopen.com/books/trends-in-modern-cosmology/the-importance-of-cosmology-in-culture-contexts-and-consequences> [accessed March 25, 2021].

²⁰⁷ Retrê, et al., *Big Ideas in Astronomy*, pp. 62-65.

²⁰⁸ Retrê, et al., *Big Ideas in Astronomy*, p. 65.

²⁰⁹ Retrê, et al., *Big Ideas in Astronomy*, p. 65.

²¹⁰ Retrê, et al., *Big Ideas in Astronomy*.

From a cultural astronomy perspective, *Big Ideas in Astronomy* as the intended guide for educators and astronomers on ‘which topics they should address in their teaching, training sessions, outreach activities or resources development’, could be challenged on the grounds of its apparent lack of cultural and indigenous inclusivity and content.²¹¹

With the trajectory of the Big Ideas appearing to be predominantly science-based, there may be an argument for this document to be directed at astrophysics rather than astronomy in its fuller sense, and a more inclusive set of ideas developed around cultural astronomy that align with curricular themes and topics, and are relatable not only to teachers, but also wider non-academic and non-science communities. The following section will therefore address the question: What role for cultural astronomy?

6. What role for Cultural Astronomy in astronomy education?

Salimpour, et al. indicated that, based on their analysis of select school curricula, there was a lack of explicit mention about astronomy from a cultural perspective, which suggests there is a case to be made for addressing cultural astronomy in school curricula as an entry point to learning about the sky in general, engaging with astronomy in its multiple forms, and discussing different world views.²¹² Starting within a framework that is familiar and relevant, and taking a culture-based pathway into astronomy, may then lead to the development of an interest in and appreciation of science. This route has the potential to engender respect for and strengthen different cultural identities, while also promoting universal principles and scientific progress, as has been suggested by Ruggles.²¹³ Additionally, cultural astronomies could be used to examine theoretically significant issues such as cultural identity and environmental awareness.

Whereas all people have some form of relationship the sky, this does not necessarily translate into a recognised connection with astronomy, possibly because of the dominant scientific framework in which it is currently presented. As the EU-UNAWA programme

²¹¹ Retrê, et al., *Big Ideas in Astronomy*, p. 8.

²¹² Salimpour, et al., ‘The Gateway Science’, p. 19.

²¹³ Ruggles, ‘Indigenous Astronomies and Progress in Modern Astronomy’, p. 15.

found, most teachers had no previous experience of teaching astronomy-related subjects and had difficulty combining cultural and scientific aspects of sky observations.²¹⁴

Salimpour, et al. also indicated that there was no previous research on the position of astronomy across the international science curricula.²¹⁵ This suggests that research on the presence of cultural astronomy content across all curricula topics (not just science curricula, and not limited to OECD curricula) is needed to establish a baseline from which recommendations could be made. Similarly, while Lee's research focused on college-level students, early years' research on whether cultural astronomy inspires curiosity and engagement, and has the potential to improve learners' interest and interaction with science/astronomy is also required.²¹⁶

Although there is a persistent focus in mainstream astronomy on STEM education (no mention is made of STEAM in the *IAU Strategic Plan 2020–2030, Big Ideas in Astronomy*, or in Salimpour, et al.'s 'Gateway Science' report), the arts and the humanities are well represented in cultural astronomy, which may not only be a useful link for making science-based astronomy more accessible, inclusive and relevant to learners, but also contribute to the transition from STEM to STEAM education.²¹⁷ This means, however, as noted by Kennedy and Odell, that teachers must be equipped to provide learners with interdisciplinary, multicultural and multi-perspective viewpoints.²¹⁸

Whereas the EU-UNAWWE report indicated that culture in astronomy education is an important topic, it also highlighted that resources on this connection are either difficult to find or there are gaps in the available materials.²¹⁹ As mentioned earlier (p. 21), astroEDU is an online database of curated astronomy education activities, which teachers are encouraged to adapt according to their linguistic and cultural needs.²²⁰ However, this is likely problematic for most teachers in terms of accessibility, and their unfamiliarity and inexperience teaching the subject. Despite being tested and peer-reviewed by astronomers and educators, none of the activities in the astroEDU database were referenced under the

²¹⁴ EU-UNAWWE, 'Final Report Summary', p. 16.

²¹⁵ Salimpour, et al., 'The Gateway Science', p. 2.

²¹⁶ Lee, 'The effects on student knowledge and engagement'; Salimpour, et al., 'The Gateway Science', p. 15.

²¹⁷ IAU, *IAU Strategic Plan 2020–2030*; Retrê, et al., *Big Ideas in Astronomy*; Salimpour, et al., 'The Gateway Science'.

²¹⁸ Kennedy and Odell, 'Engaging students in STEM education', p. 256.

²¹⁹ EU-UNAWWE, 'Final Report Summary', p. 30.

²²⁰ astroEDU, <https://astroedu.iau.org/en/> [accessed March 25, 2021].

search words ‘culture’/‘cultural’, ‘tradition’/‘traditional’, ‘myth’, ‘cosmology’ or ‘indigenous’, suggesting that this is an area where cultural astronomy could offer input on supplementary content.²²¹ The EU-UNAWAWE report also drew attention to the fact that many stories about astronomy in indigenous cultures have not yet been recorded.²²² This is another area that, for educational purposes, may best be curated from an interdisciplinary cultural astronomy perspective rather than a science-dominant one.

The issue of cultural neutrality needs to be addressed in astronomy education, which not only biases ‘universal’ science astronomy, but also raises questions about who is controlling the narrative informing policy and curricula. As such, it is also important to consider whose views and interests are being conveyed in the content curation of available astronomy education resources, as well as accessibility to such resources, which may also be problematic as many are only available online. A predominance of science-focused astronomy content suggests that there is a need for culturally relevant resources to be developed outside the science agenda framework, which could also be utilised in informal education settings and in community-centred approaches to learning.

While many astronomy education projects have received substantial funding to create resources and train teachers, it is clear from Salimpour, et al.’s research findings that these have not wholly encompassed cultural or indigenous astronomies.²²³ This suggests that, if these perceived ‘non-science’ astronomies built up a stronger presence, future astronomy education research may reflect greater representation and equity in the classroom.²²⁴ It is also likely that cultural astronomy education research could make a significant contribution to decolonising science, which, as Lee has pointed out, is an important focus of contemporary research.²²⁵ Another cultural astronomy education research area to consider would be whether community-centred cultural astronomy curricula, similar to that suggested by Keane in terms of teaching indigenous knowledge in the science classroom, would offer any benefits over learner-centred curricula.²²⁶

²²¹ IAU, *IAU Strategic Plan 2020–2030*, 41; astroEDU, <https://astroedu.iau.org/en/> [accessed March 25, 2021]

²²² EU-UNAWAWE, ‘Final Report Summary’, p. 30.

²²³ UNAWAWE, ‘Universe Awareness’; EU-UNAWAWE, ‘Final Report Summary’, p. 2; Salimpour, et al., ‘The Gateway Science’, p. 19.

²²⁴ Salimpour, et al. ‘The Gateway Science’, p. 19.

²²⁵ Lee, ‘The effects on student knowledge and engagement’, p. 14.

²²⁶ Keane, ‘Science education and worldview’, p. 610.

That astronomy holds wide public appeal, which is mostly driven by popular media, suggests that cultural astronomy could also engage with adult learners who are interested in astronomy but do not have a science background. This also points to cultural astronomy having relevance beyond Gullberg's notion of it offering historical and cultural insights to working astronomers.²²⁷ Contemporary aspects of astronomy, such as science fiction media and terrestrial-based space tourism, are also potential entry points for engaging learners' curiosity. Similarly, astrology should not necessarily be dismissed as a way of attracting learners' attention.²²⁸

In summary, increased recognition of cultural astronomy as a discipline and the role it can play in astronomy education and research may be key to setting out a pathway of understanding integral to transdisciplinary learning and broadening the scope of the global astronomy endeavour. This would take astronomy beyond the science-dominant agenda evident in the *IAU Strategic Plan 2020–2030* and *Big Ideas in Astronomy*. As such, the current iteration of *Big Ideas in Astronomy* cannot be interpreted as representative of all astronomies, with cultural aspects only being interpreted within scientific or historical contexts.

7. Summary and Conclusion

This research initially considered aspects of the science–culture divide and academic perspectives on whether science can be separated from its context. The views of several theorists were considered and, while O'Neill claimed not to find the fissures between the natural sciences and the humanities that Snow had previously indicated, Harding argued that science was embedded in western ethnocentrism and that only those who practice western scientific rationality exercised critical reason. Cajete countered this by suggesting the western world view was a 'dysfunctional cosmology' that required indigenous knowledge to recontextualise its knowledge to make it meaningful, but El-Hani and Bandeira called for indigenous knowledge not to be cast as a science as this would likely remove it from the context in which it finds its legitimacy. However, an anomaly is apparent in UNESCO's nesting of indigenous knowledge in a scientific rather than a

²²⁷ Gullberg, 'Cultural astronomy and educational opportunities', p. 812.

²²⁸ Retrê, et al., *Big Ideas in Astronomy*, p. 20; Turgut, 'The Context of Demarcation', p. 508.

cultural context, and the definition of science as advanced by the Science Council, which is not inclusive of culture, suggests that a science–culture divide likely remains.

Recent literature on school-level science and astronomy education was also reviewed, with specific reference to the ROSE project, the shift from STEM to STEAM education, the IAU’s involvement in astronomy education, and the development of *Big Ideas in Astronomy*, which are intended to inform school curricula, assessment, teacher training and resource development. Although it has been suggested that astronomy is the ‘gateway science’, Salimpour, et al.’s research indicated that this was a hypothesis that still required validation.

It was found that the minimal cultural content in *Big Ideas in Astronomy*, of which the IAU’s Office of Astronomy Education is now custodian, was framed predominantly in scientific or historic contexts. Contemporary aspects of cultural astronomy and indigenous knowledge have seemingly been overlooked, despite programmes such as EU-UNAWA indicating that culture in astronomy education is an important topic, and research on culturally responsive astronomy education highlighting that this approach encourages learners to become more engaged and learn more about science/astronomy.

An outline was offered of the position of cultural astronomy at the science–culture interface before addressing the universal sky / diverse cultures dichotomy and whether, as one of Buxner and Holbrook’s respondents had suggested, talking of the universality of the sky would destroy local culture and cultural diversity. Against this background, and Ruggles’ indication that indigenous and cultural astronomy are gaining momentum and recognition as interdisciplinary academic disciplines, the question asked was: What role for cultural astronomy in astronomy education? Suggestions for ways in which cultural astronomy could impact astronomy education were discussed in section 6.

Although the science–culture divide may appear to be being perpetuated, the multidisciplinary of cultural astronomy makes it well positioned at the interface as both a promoter of and an antidote to ‘universal science’, and to challenge the idea of the scientist as the only conduit of truth and value. Such an approach, drawing on different ways of knowing, may also go some way to resolving the issues of underrepresentation, inclusivity, equity and equality in astronomy that have been identified by the IAU.

Whereas Salimpour, et al. indicate that the validity of astronomy as the ‘gateway science’ is still being tested, an argument could be made for cultural astronomy as the ‘gateway astronomy’, with broad appeal to learners who might not otherwise consider engaging with science or astronomy as taught subjects. As the ROSE project findings revealed, approaching the teaching of science (or in this case astronomy) by making relevant human/cultural connections appears to help learners not only relate to the content, but also produce positive results. Raising the platform of cultural astronomy education research outside the hierarchy, or what Midgley called ‘academic narrowness’, connected to the exalted status of Western science, and developing appropriate and relevant content that can be taught either independently or embedded in existing school curricula, will likely go some way to enriching the field of astronomy as a whole, inspire a lifelong interest in the sky as part of local culture, offer a basis for examining different world views, and potentially attract learners to scientific astronomical enquiry.

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Appendices

Appendix I: A summary of the goals, priority areas and actions in the IAU's Strategic Plan 2020–2030

Goal 1 The IAU leads the worldwide coordination of astronomy and the fostering of communication and dissemination of astronomical knowledge among professional astronomers.	
I. Stimulate and facilitate sharing of astronomical knowledge among professional astronomers	Action: - The IAU will expand membership to include the category of Junior Members for early career astronomers, and will stimulate activities fostering their professional development. - The EC will continue IAU-related publications and communications, using and promoting updated methods.
II. Coordinate professional tasks and interact with other fields at the professional level	Action: - The Working Group on Global Coordination will have a focus meeting at the Gas and a focused workshop between GAs. - The IAU will organise an international conference on dark and quiet sky protection, in cooperation with COPUOS and UNESCO, as well as follow-up meetings and interactions with IUCN, to raise awareness at all levels. - The IAU will continue to foster connections with relevant professional organisations to help advance science. - The IAU will continue to oversee official assigning of names for celestial bodies and their features. - The IAU will continue to oversee the definition, determination, and use of astronomical standards.
III. Recognise excellence in astronomy through prizes	Action: The IAU will continue to enhance and diversify its portfolio of prizes to reflect changes in its priorities.
Goal 2 The IAU promotes the inclusive advancement of the field of astronomy in every country.	
IV. Foster inclusiveness in the advancement of astronomy	Action: - The IAU will continue to increase the level of actions to promote diversity, encourage and retain women and minorities in astronomy, and support astronomers with special needs. - WiA and ICSU will cooperate on the Gender Gap in Science study and similar future studies to promote best practices for achieving gender parity. - IAU-sanctioned events will follow anti-harassment guidelines.
V. Facilitate the advancement of the next generation of astronomers and scientists	Action: The OYA will hold as many as 4 ISYA schools every 2-year period.
Goal 3 The IAU promotes the use of astronomy as a tool for development in every country.	
VI. Stimulate global development through the use of astronomy	Actions: - Contribute significantly to at least half of all SDG indicators; develop a number of global OAD "signature" projects. - Establish enough regional offices to cover all populated regions of the world. - Refine the OAD project evaluation and feedback loop. - Use astronomy and its technology to position young people for career opportunities throughout society. - Establish interdisciplinary partnerships around science for development. - Source the necessary funding to realise the above and assist other related initiatives in fundraising.

Goal 4 The IAU engages the public in astronomy through access to astronomical information and communication of the science of astronomy.	
VII. Engage the public in astronomy	Action: • Increase the network of NOCs; restructure and ensure their effectiveness. • Facilitate international communication through exchanges and translations. • Provide open databases and public-friendly access to astronomical information. • Encourage communication of science and critical thinking through IAU member public engagement, professional-amateur, and citizen science activities. • Promote dark skies and the pale blue dot message.
Goal 5 The IAU stimulates the use of astronomy for teaching and education at school level.	
VIII. Use astronomy for teaching and education at school level	Action: Create an Office of Astronomy for Education, which will: • establish a network of NAECs • analyse the use of astronomy in teaching in IAU countries and identify accessible materials and astronomy literacy guidelines • encourage standards for teacher training activities • organise an annual International School for Astronomy Education (ISAE) • build a database of volunteer IAU members.

Appendix II: Summary of the Big Ideas in Astronomy (adapted from Retrê, et al., 2019)

1. Astronomy is one of the oldest sciences in human history	1.1 Understanding the sky and the movements of the Sun and planets was one of the first attempts to understand the natural world 1.2 Earlier cultures imagined patterns connecting stars in the night sky 1.3 Astronomy provided important timekeeping knowledge, essential for ancient agriculture 1.4 Astronomy was important for navigators in the past 1.5 Astronomy, by using the scientific method, is different from astrology 1.6 Earth was believed, by some earlier cultures, to be the centre of the Universe 1.7 The century-long Copernican revolution led to the Sun replacing the Earth as the accepted centre of the Solar System 1.8 Over 400 years ago, astronomers undertook the first methodical observations within astronomy using a telescope 1.9 The Earth is approximately spherical in shape, and this has been demonstrated for centuries in many different ways
2. Astronomical phenomenon can be experienced in our daily lives	2.1 We experience day and night because of Earth's rotation around itself 2.2 We experience seasons because of the tilt of Earth's axis of rotation as the Earth moves around the Sun in a year 2.3 We see different phases of the Moon throughout a Moon cycle 2.4 Eclipses occur due to special alignments of the Earth, the Sun and the Moon 2.5 The tides on Earth are a result of the gravity of the Sun and Moon 2.6 Light from the Sun is essential for most life forms on Earth 2.7 Particles from the Sun travel to the Earth and cause the auroras 2.8 Technology developed for astronomical research is part of our daily life
3. The night sky is rich and dynamic	3.1 We can see several thousands of stars with our eyes on a clear and dark night 3.2 All the stars we see with the unaided eye belong to our galaxy 3.3 The night sky can help you to orient yourself on Earth and navigate 3.4 The rotation axis of Earth wobbles (precesses) over thousands of years 3.5 Only a few celestial bodies are bright enough to be seen with the unaided eye when the Sun is above the horizon 3.6 Celestial objects rise in the East and set in the West due to the Earth's rotation 3.7 Stars twinkle due to our atmosphere 3.8 Millions of meteors enter the Earth's atmosphere daily
4. Astronomy is a science that studies celestial objects and phenomena in the Universe	4.1 Light (otherwise known as electromagnetic radiation) is the main source of information for astronomical research 4.2 On large scales, gravitation is the dominant interaction in the Universe 4.3 Gravitational waves and subatomic particles provide new ways of studying the Universe 4.4 Astronomy makes use of data obtained from observations and simulations to model astronomical phenomena in the framework of current theories 4.5 Astronomical research combines knowledge from different fields, such as physics, mathematics, chemistry and biology 4.6 Astronomy is divided into a number of specialties 4.7 Time and distance scales in astronomy are a lot larger than the ones we use in our daily life 4.8 Spectroscopy is an important technique allowing us to probe the Universe from a distance
5. Astronomy benefits from and stimulates technology development	5.1 Telescopes and detectors are crucial to the study of Astronomy 5.2 Some smaller telescopes can be linked together to act as one big telescope 5.3 Astronomical observatories are located on Earth and in Space 5.4 Earth-based astronomical observatories are often located in remote regions all around the world 5.5 Astronomy today is part of "Big Science" and "Big Data" 5.6 Complex simulations and huge data in astronomy require the development of powerful supercomputers 5.7 Astronomy is a global science, with international teams, and where data and publications are shared freely 5.8 Numerous spacecrafts have been launched to space to study the Solar System

6. Cosmology is the science of exploring the Universe as a whole	6.1 The Universe is about 13.8 billion years old 6.2 The evolution of the Universe can be explained by the Big Bang model 6.3 The Universe is mainly composed of Dark Energy and Dark Matter 6.4 The Universe is expanding 6.5 The Universe is homogeneous and isotropic 6.6 The natural laws (e.g. gravity) that we study on Earth appear to work the same way throughout the Universe 6.7 We can only directly observe a fraction of the total Universe 6.8 Astronomers always observe the past 6.9 The Cosmic Microwave Background allows us to explore the early Universe 6.10 The expansion of space causes light from distant galaxies to be shifted 6.11 The large-scale structure of the Universe is composed of filaments, sheets and voids
7. We all live on a small planet within the Solar System	7.1 The Solar System was formed about 4.6 billion years ago 7.2 The Solar System is composed of the Sun, planets, moons, comets, asteroids, and icy bodies 7.3 There are eight planets in the Solar System 7.4 There are several dwarf planets in the Solar System 7.5 The planets are divided into terrestrial (rocky) planets and gas giants 7.6 Some planets have dozens of natural satellites 7.7 Earth is the third planet orbiting around the Sun, and has one natural satellite, the Moon 7.8 There are millions of asteroids which are remnants from the early formation of our Solar System 7.9 A comet is an icy object that acquires a tail when it is heated by the Sun 7.10 The Solar System has different boundary regions, one of which is called the Heliopause
8. We are all made of stardust	8.1 A star is a self-luminous body generating its energy by internal nuclear reactions 8.2 Stars form from massive clouds of dust and gas 8.3 The closest star to Earth is the Sun, which has a moderate size and mass, neither big nor small, compared to other stars 8.4 The colour of a star tells us its surface temperature 8.5 The space between stars can be largely empty or it can contain clouds of gas, which can produce new stars 8.6 A star goes through a life cycle which is largely determined by its initial mass 8.7 Massive stars end their life cycle as stellar black holes 8.8 New stars and their planetary systems are born from matter left behind by previous stars in that region 8.9 The human body consists of atoms that can be traced back to earlier stars
9. There are hundreds of billions of galaxies in the Universe	9.1 A galaxy is a large system of stars, dust and gas 9.2 Galaxies contain large amounts of Dark Matter 9.3 Galaxy formation is an evolutionary process 9.4 There are three main types of galaxies: Spiral, Elliptical and Irregular 9.5 We live in a spiral galaxy called the Milky Way 9.6 The spiral arms of galaxies are created by pile-ups of gas and dust 9.7 Most galaxies have a supermassive black hole at their centre 9.8 Galaxies can be extremely distant from each other 9.9 Galaxies form clusters 9.10 Galaxies interact with each other through gravity
10. We may not be alone in the Universe	10.1 Organic molecules have been detected outside Earth 10.2 Living organisms have been found to survive in extreme environments on the Earth 10.3 Traces of liquid water open up the possibility of primitive life on Mars 10.4 Some natural satellites in the Solar System [Europa, Titan] appear to have the conditions for life to exist 10.5 There are numerous planets called exoplanets, which orbit stars other than the Sun 10.6 Exoplanets can be very diverse and are often found in systems 10.7 We are now close to the detection of an Earth-like planet 10.8 Scientists are searching for extraterrestrial intelligence

11. We must preserve Earth, our only home in the Universe	11.1 Light pollution affects humans, many other animals and plants 11.2 There is a lot of human-made debris in Earth's orbit 11.3 We monitor potentially hazardous space objects 11.4 Humans have a significant impact on the Earth's environment 11.5 The climate and the atmosphere are heavily affected by human activity 11.6 A global perspective is necessary to preserve our planet 11.7 Astronomy provides us with a unique cosmological perspective that reinforces our unity as citizens of the Earth
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