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Fashioned in the light of physics: the scope and methods of Halford Mackinder's geography

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Abstract. Throughout his career the geographer, and first reader in the 'new' geography at the University of Oxford, Halford Mackinder (1861–1947) described his discipline as a branch of physics. This essay explores this feature of Mackinder's thought and presents the connections between him and the Royal Institution professor of natural philosophy John Tyndall (1820–1893). My reframing of Mackinder's geography demonstrates that the academic professionalization of geography owed as much to the methods and instruments of popular natural philosophy and physics as it did to theories of Darwinian natural selection. In tracing the parallels between Tyndall and Mackinder, and their shared emphasis upon the technology of the magic lantern and the imagination as tools of scientific investigation and education, the article elucidates their common pedagogical practices. Mackinder's disciplinary vision was expressed in practices of visualization, and in metaphors inspired by physics, to audiences of geographers and geography teachers in the early twentieth century. Together, these features of Mackinder's geography demonstrate his role as a popularizer of science and extend the temporal and spatial resonance of Tyndall's natural philosophy.

Introduction

In their portrayals of Halford Mackinder (1861–1947), scholars identify, but do not thoroughly investigate, the influence of several individuals. The latter includes Henry Nottidge Moseley (1844–1891), naturalist on the HMS *Challenger* expedition (1872–1876), and professor of comparative anatomy on Mackinder's Oxford Natural Sciences undergraduate course.[1] The Royal Geographical Society (RGS) secretary, Henry Walter Bates (1825–1892), and RGS officer and Victorian experimental scientist Francis Galton (1822–1911) constitute further influences.[2] Mackinder, however, rarely referred to them. On several occasions Mackinder did refer to one individual whose importance for geography has been overlooked. Perhaps because he was neither a

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1 Brian Blouet, *Halford Mackinder: A Biography*, College Station: Texas A & M University Press, 1987, 24–25, 41.

2 David R. Stoddart, '"That Victorian science": Huxley's physiography and its impact on geography', *Transactions of the Institute of British Geographers* (1975) 66, pp. 17–40; Stoddart, 'The RGS and the "new geography": changing aims and changing roles in nineteenth century science', *Geographical Journal* (1980) 146, pp. 190–202; Blouet, op. cit. (1), pp. 19–24.

trained geographer nor active within the RGS, the natural philosopher John Tyndall (1820–1893) has been neglected by geography's historians.[3]

This article elucidates the extent to which Tyndallian natural philosophy and physics fashioned Mackinder's pedagogical methods and definitions of geography. Simon Schaffer has linked the 'the end of natural philosophy' to the professionalization of physics in the nineteenth century and to historiographers' 'reification of heroic discoverers and prized techniques by these new research schools'.[4] However, aspects of natural philosophy persisted in nineteenth-century popular and professional geographical practices. In arguing for the fashioning of Mackinder by Tyndall, my essay is informed by Richard Powell's positioning of geographical experience and practice between the poles of physics and anthropology.[5] It also draws from Richard Staley's investigation into how physics shaped Franz Boas (1858–1942) and Bronislaw Malinowski (1884–1942), and their practices in geography and anthropology and in anthropology respectively. The 'fundamental lines of thought and action', Staley contends, 'are determined by our early education' and 'form the subconscious basis of all our activities'. In transferring their intellectual interests to the practice of anthropology, Staley argues, Boas and Malinowski did not withdraw from physics. Instead 'significant elements of its inheritance remained not only in their dreams, but also in their defining aims'.[6] This, too, is a framing perspective for what follows.

In exploring the light-conducting educational instruments favoured by Tyndall and Mackinder, including the magic lantern, my inquiry enriches understandings of the relations between technology and theory in histories of science.[7] What follows compares the ways in which this iconic medium of Enlightenment natural philosophy, too often overshadowed by studies of the telescope and microscope, fashioned Tyndall and Mackinder's rhetoric, and the imagery of their geographical imaginations.[8] My assessment is informed by Diarmid Finnegan's exposition of nineteenth-century science lectures and the oratorical techniques of Tyndall's close associates, Michael Faraday (1791–1867) and Thomas Henry Huxley (1825–1895).[9] This work has shown the authority of audiences in receiving, even shaping, public knowledge. Yet demonstration

3 Ursula Deyoung, *A Vision of Modern Science: John Tyndall and the Role of the Scientist in Victorian Culture*, New York: Palgrave Macmillan, 2011.

4 Simon Schaffer, 'Scientific discoveries and the end of natural philosophy', *Social Studies of Science* (1986) 16, pp. 387–420, 413.

5 Richard C. Powell, 'The study of geography? Franz Boas and his canonical turns', *Journal of Historical Geography* (2015) 49, pp. 21–30.

6 Franz Boas, *The Mind of Primitive Man*, New York: MacMillan, 1911, 240, quoted in Richard Staley, 'Conversions, dreams, defining aims? Following Boas, Malinowski, physics and anthropology, through laboratory and field', *History of Anthropology Newsletter* (2012) 39, pp. 1–10, 5, 1.

7 Jed Z. Buchwald and Sungook Hong, 'Physics', in David Cahan (ed.), *From Natural Philosophy to the Sciences: Writing the History of Nineteenth-Century Science*, Chicago: The University of Chicago Press, 2003, pp. 163–195, 180–181.

8 Koen Vermeir, 'The magic of the magic lantern (1660–1700): on analogical demonstration and the visualization of the invisible', *BJHS* (2005) 38(2), pp. 127–159; Cristián Simonetti, 'Weathering climate: telescoping change', *Journal of the Royal Anthropological Institute* (2019) 25, pp. 241–264, 252.

9 Diarmid A. Finnegan, 'Finding a scientific voice: performing science, space and speech in the 19th century', *Transactions of the Institute of British Geographers* (2016) 42, pp. 1–14, 12.

instruments such as the lantern, and the impact of that technology on visualizing practices employed by its users, have not been not scrutinized.[10]

The paper, then, assesses how systems of knowledge fashion sciences and specific audiences' understandings and participation in them. As historians of education Ian Grosvenor, Martin Lawn and Kate Rousmaniere note, we can pinpoint textbook publication dates but 'the meaning and practice of work to the teacher lie out of reach, along with the culture and politics of their social and educational existence'.[11] With reference to Tyndall's *Six Lectures on Light* (1885) and Mackinder's publications, notably *The Teaching of Geography & History: A Study in Method* (1914), this essay reassesses the impact of Tyndall's expository practices in relation to the professionalization and popularization of geographical science.[12] In doing so I argue for an ontological, epistemological and pedagogical link between physics and geography deeper than has previously been appreciated.

Mackinder in the history and historiography of geography

Scholars have scrutinized Mackinder's intellectual and academic development, politics and life course, and to a lesser extent his methodological innovations. Yet throughout this extensive scholarship the significance of Tyndall and physics in Mackinder's geography has been overlooked. Mackinder's university studies and academic career have been surveyed.[13] His school studies in chemistry, physics and biology at Epsom College, Surrey, have been identified.[14] His prize-winning essays – 'A glimpse of A.D. 1950' and 'Geological Epsom' – demonstrate an aptitude for succinct synthesis and the sharp visual narration of time and space in a style reminiscent of popular dissolving-view lantern performances and an interest in light technologies.[15] After taking a first in natural sciences (with a specialization in biology) at Oxford, Mackinder's junior scholarship enabled him to study modern history. He did so, allegedly, to test the theory of natural selection against human development.[16] Despite this range of studies, according to Osbert Howarth, it was said of Mackinder 'by historians that he

10 Finnegan, op. cit. (9).

11 Ian Grosvenor, Martin Lawn and Kate Rousmaniere, 'Introduction', in Grosvenor, Lawn and Rousmaniere (eds.), *Silences and Images: The Social History of the Classroom*, New York: Peter Lang, 2014 (first published 1999), pp. 1–10, 8

12 John Tyndall, *Six Lectures on Light Delivered in the United States in 1872–73*, 4th edn, London: Longmans, Green, and Co., 1885; Halford J. Mackinder, *The Teaching of Geography & History: A Study in Method*, London: G. Philip & Son, 1914.

13 E.W. Gilbert, 'The Right Honourable Sir Halford J. Mackinder, P.C., 1861–1947', *Geographical Journal* (1947) 110, pp. 94–99.

14 [H. Mackinder], typed draft of Mackinder's autobiography, undated, Bodleian Library School of Geography (henceforth BLSG), Box 88, 27.

15 H.J. Mackinder, 'A glimpse of A.D. 1950', *The Epsomian* (1877) 7, n.p.; and Mackinder, 'Geological Epsom,' *The Epsomian* (1880) 10, n.p.; Joss Marsh, 'Dickensian "dissolving views": the magic lantern, visual story-telling, and the Victorian technological imagination', *Comparative Critical Studies* (2009) 6(3), pp. 333–346.

16 Edmund W. Gilbert, 'Seven lamps of geography: an appreciation of the teaching of Sir Halford J. Mackinder', *Geography* (1951) 36, pp. 21–43, 28; Blouet, op. cit. (1), p. 26.

knew no history, by geologists that he knew no geology, by climatologists that he knew no climatology'.[17]

Early scholarship deemed that as an undergraduate Mackinder was 'relatively uninterested in evolution and unaffected by Darwinism [when] the movement was gathering momentum in the universities in the 1880's'.[18] However, following the centenary of the publication of Charles Darwin's *Origin of Species*, historians overdetermined the influence of natural-selection theory upon later nineteenth-century British geography.[19] By pursuing 'the Darwinian revolution', geographers started to reveal the longevity and plurality of the concept of physiography. Although the term was variously employed by Immanuel Kant and Alexander von Humboldt, Huxley's *Physiography: An Introduction to the Study of Nature* (1877) offered an extensive exposition of this concept. Based on a series of Huxley's lectures inspired by German *Erdkunde*, or physical geography, *Physiography* outlined the structure of the Earth, its relation to other bodies, and features of winds, tides, rivers, mountains and plains.[20] Nevertheless, in illuminating the overlaps and contradictions between Huxley's physiography and the burgeoning, equally plural, 'new' geography, scholars have overlooked the influence of Tyndall's natural philosophy and that of emergent physics practices on Mackinder.

Mackinder's attention to visuality has been noted and the transformation of his conceptualization of geographical practice from a science to an art and philosophy has been observed.[21] Further exploration of these shifts supported the argument that Mackinder was influenced by a 'British scientific-exploratory tradition' carried out in the field which sought to apprehend the physical environment of the whole globe.[22] More recently, his martial and imperial instincts have been mapped.[23] Yet scholars have also asserted that his politics were charged with romanticism. The latter have been viewed as a catalyst for his 'social-imperialist vision of education' and desire to forge an 'efficient national workforce'.[24] Finally, Mackinder's philosophy has been summarized as an 'organic

17 Osbert J.R. Howarth, 'The centenary of Section E (Geography)', *Advancement of Science* (1951) 8, pp. 151–165, 150; in Stoddart, 'The RGS and the "new geography"', op. cit. (2), p. 199; William Henry Parker, *Mackinder: Geography as an Aid to Statecraft*, Oxford: Clarendon Press, 1982, 260.

18 L.M. Cantor, 'Halford Mackinder: his contribution to geography and education', MA thesis, University of London, 1960, 254.

19 David Cahan, 'Looking at nineteenth-century science: an introduction', in Cahan, op. cit. (7), pp. 3–15, 9; Stoddart, 'The RGS and the "new geography"', op. cit. (2), pp. 190–202.

20 T.H. Huxley, *Physiography: An Introduction to the Study of Nature*, London: Macmillan & Co., 1877. 'The term "physiography" does not appear in the printed manuscript text of the 1869 course, but it forms the sub-title for the printed syllabus of the course given in 1870'. Stoddart, 'That Victorian science', op. cit. (2), p. 19.

21 Cantor, op. cit. (18), p. 326.

22 Blouet, op. cit. (1), p. 41.

23 Parker, op. cit. (17); Gerry Kearns, *Geopolitics and Empire: The Legacy of Halford Mackinder*, Oxford: Oxford University Press, 2009.

24 Gearóid Ó Tuathail, 'Putting Mackinder in his place', *Political Geography* (1992) 2, pp. 100–118, 115, 108.

conservative ideology' and the man himself has been deemed 'a political economist with a holistic viewpoint' whose unifying vision resided in natural phenomena.[25]

Scholars now understand that the identities of the sciences are not defined solely by the establishment of university disciplines.[26] Other histories of geography than the above Whiggish approaches have identified the retrospective separation of nineteenth-century social and earth sciences.[27] The qualification of Mackinder's geographical practice as 'new' has been undermined by Robert Mayhew's survey of pedagogical texts from the early modern period to the late nineteenth century.[28] A vibrant discursive, rather than disciplinary, tradition of geography existed in British university mathematics, natural philosophy and history before geography was institutionalized as an independent science. Mackinder is understood as having steered geography away from an 'essentially humanist conception of education and the curriculum'.[29]

It has been argued that the richly variegated nineteenth-century landscape of geographical knowledge production across Britain has been 'underplayed, at worst neglected, even as it is partially remembered'.[30] Before Mackinder's appointment to the Oxford readership, contributions to scientific practices were made via entertaining and educational public lecture performances. From the 1830s the British Association for the Advancement of Science (BAAS), and from 1851 BAAS Geography Section E, promulgated scientific methodologies within a civic, rather than institutional or academic, context. More generally, nineteenth-century education saw a shift in scholarly focus from humanist to scientific expository practices.[31] It has therefore been suggested that Mackinder's readership was less a foundational moment than a consequence of pre-existing, wider-reaching intellectual transformations.[32]

Although throughout the nineteenth century geography straddled both the social and the earth sciences, the subject was in 'reconnaissance' mode and lacked overarching principles.[33] However, in post-Darwinian science greater emphasis was placed upon

25 Ó Tuathail, op. cit. (24), p. 100; Peter J. Taylor, *Political Geography: World-Economy, Nation-State and Locality*, 2nd edn, London: Longman, 1989, 49; in Ó Tuathail, op. cit. (24), p. 102. Halford J. Mackinder, 'The teaching of geography and history as a combined subject', *Geographical Teacher* (1913) 7, pp. 4–19; Mackinder, 'Geography as a pivotal subject in education', *Geographical Journal* (1921) 57, pp. 376–384; Mackinder, 'The music of the spheres', *Proceedings of the Royal Philosophical Society* (1937) 63, pp. 170–181; in Ó Tuathail, op. cit. (24), p. 114.

26 Cahan, op. cit. (19), p. 10.

27 Cahan, op. cit. (19), p. 11.

28 Robert Mayhew, 'Halford Mackinder's "new" political geography and the geographical tradition', *Political Geography* (2000) 19, pp. 771–791, 787.

29 Charles W.J. Withers and Robert J. Mayhew, 'Rethinking "disciplinary" history: geography in British universities, *c.*1580–1887', *Transactions of the Institute of British Geographers* (2002) 27, pp. 11–29, 20.

30 Charles W.J. Withers, Diarmid Finnegan and Rebekah Higgitt, 'Geography's other histories? Geography and science in the British Association for the Advancement of Science', *Transactions of the Institute of British Geographers* (2006) 31, pp. 433–451, 435.

31 John Guillory, 'Literary study and the modern system of the disciplines', in Amanda Anderson and Joseph Valente (eds.), *Disciplinarity at the Fin de Siècle*, Princeton, NJ and Oxford: Princeton University Press, 2002, pp. 19–44.

32 Rebekah Higgitt and Charles W.J. Withers, 'Science and sociability: women as audience at the British Association for the Advancement of Science, 1831–1901', *Isis* (2008) 99, pp. 1–27.

33 Cahan, op. cit. (19), p. 10.

methods, laws and anomalies. Staley notes that scientific approaches were ‘dominated by law (like physics) or by description (like geography)’.[34] In this regard Tyndall’s investigations of glacier dynamics epitomized the former. Recent work has investigated the methodology, instruments and practices of geographical science. Yet despite apprehending the diversity of Mackinder’s geography, historians have not studied his pedagogical methods.[35] Nor have they considered his use, in this context, of the magic lantern for the purposes of making and communicating scientific knowledge. It is therefore to the use of that instrument that we now turn.

Nineteenth-century science and the lantern

Founded in 1799, the Royal Institution (RI) was amongst the most popular of the London savant societies.[36] As academic practices of physics shifted in Britain towards bespoke academic laboratories and developed around experiments with new instruments, the RI maintained a tradition of scientific showmanship and natural philosophy for middle-class audiences.[37] In the second half of the century, its lectures – many highly visual – helped to sustain science.[38] Tyndall first lectured at the RI in 1853 and subsequently became the professor of natural philosophy there. From 1858 he and Michael Faraday, the Fullerian Professor of Chemistry, lectured with the lantern.[39] In 1869 Tyndall lectured with this instrument in a series of performances published the following year as *Nine Lectures on Light*.[40] The lantern’s ‘convenient and controllable light source for public demonstrations’ became integral to his lectures from 1872, when his fame was at its zenith.[41] During a lecture tour of the USA that year, Tyndall’s skilful manipulation of the lantern, described as ‘a camera’, made headline news.[42]

Within nineteenth-century regimes of truth and their empiricist scientific methods of evidencing, visual media such as lanterns and cameras were both privileged and regarded with suspicion. Although lantern projections came to prominence across the country, the RI’s courting of popular audiences in its fashionable Friday discourses led to criticism.[43]

34 Staley, op. cit. (6), p. 5; Stoddart, ‘That Victorian science’, op. cit. (2), p. 18.

35 C.W.J. Withers, ‘Science, scientific instruments and questions of method in nineteenth-century British geography’, *Transactions of the Institute of British Geographers* (2013) 38, pp. 167–179.

36 Frank M. Turner, *Between Science and Religion: The Reaction to Scientific Naturalism in Late Victorian England*, New Haven, CT and London: Yale University Press, 1974.

37 Cahan, op. cit. (19), p. 9.

38 Michael Reidy, *Introduction: John Tyndall, Scientific Naturalism and Modes of Communication*, in Bernard Lightman and Michael Reidy (eds.), *The Age of Scientific Naturalism*, London: Pickering & Chatto, 2014, pp. 1–13, 4.

39 Jeremy Brooker, ‘A lecture on Locust Street, Morton, Tyndall, Pepper, and the construction of scientific reputation’, in Carin Berkowitz and Bernard Lightman (eds.), *Science Museums in Transition: Cultures of Display in Nineteenth-Century Britain and America*, Pittsburgh: University of Pittsburgh Press, 2017, pp. 111–138, 125.

40 Brooker, op. cit. (39), p. 132.

41 Reidy, op. cit. (38), p. 1.

42 Thomas L. Hankins and Robert J. Silverman, *Instruments and the Imagination*, Princeton, NJ: Princeton University Press, 1995, 69; Irena McCabe, ‘Second best as a researcher, second to none as a populariser? The atmospheric science of John Tyndall FRS (1820–1893)’, PhD dissertation, UCL, 2012, 52.

43 Deyoung, op. cit. (3), p. 15.

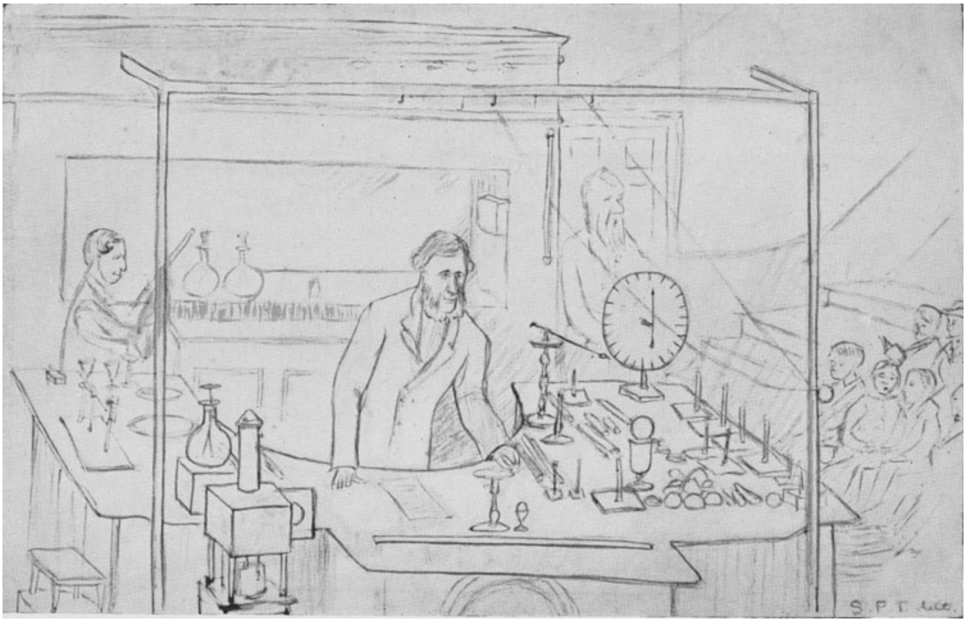

Figure 1. 'Professor Tyndall lecturing to a juvenile audience at the Royal Institution, 1876'. From a pen-and-ink sketch by Silvanus P. Thompson in Jane S. Thompson and Helen G. Thompson, *Silvanus P. Thompson, His Life and Letters* (London: Fisher Unwin, 1920, p. 22), reproduced by kind permission of the Syndics of Cambridge University Library.

Jill Howard's scholarship has argued that RI audiences were actually the real 'co-stars' of scientific performances.[44] Whether at the RI or in BAAS meetings, in the laboratory or the lecture theatre, audiences were as vital to the making and shaping of science as the elements in the experiments performed.[45]

The lantern, a common feature of spectacular entertainments for general audiences attending the London Royal Polytechnic Institution (RPI) shows, was also used by Tyndall in children's lectures.[46] The physical investigator Oliver Lodge's (1851–1940) recollections of the Christmas lectures he attended as a child evidence Tyndall's impact upon the next generation of scientific practitioners.[47] Physicist John William Strutt (1842–1919) similarly remembered the popular-science performances at the RPI.[48]

44 Bernard V. Lightman, *Victorian Popularizers of Science: Designing Nature for New Audiences*, Chicago: The University of Chicago Press, 2007, vii; Jill Howard, '"Physics and fashion": John Tyndall and his audiences in mid-Victorian Britain', *Studies in History and Philosophy of Science* (2004) 35, pp. 729–758, 755.

45 Aileen Fyfe and Bernard V. Lightman (eds.), *Science in the Marketplace: Nineteenth-Century Sites and Experiences*, Chicago: The University of Chicago Press, 2007.

46 Howard, op. cit. (44), p. 736; Jeremy Brooker, *The Temple of Minerva: Magic and the Magic Lantern at the Royal Polytechnical Institution, London 1837–1901*, Rippon: The Magic Lantern Society, 2013.

47 Howard, op. cit. (44), p. 754; Staley, op. cit. (6), p. 1–2, 5.

48 John Strutt, *Life of Lord Rayleigh*, London: Edward Arnold & Co., 1924; in Iwan R. Morus, 'Seeing and believing science', *Isis* (2006) 97, pp. 101–110, 109.

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Despite his considerable fame, Tyndall, as Ursula Deyoung argues, was 'half-forgotten by the next generation of scientists': his research, lecturing and experimenting methods had become outdated.[49] Within a few decades of his death in 1893 geographies of scientific practice shifted and university laboratory demonstrations outshone the RI's experimental practices.

The RI also contributed to the promotion of geographical knowledge. Geologist and four-time president of the RGS Sir Roderick Murchison (1792–1871) sat on the RI board of managers in the 1870s.[50] When the RGS was still without a permanent home, Murchison engineered the hire of the RI lecture theatre for the RGS's Monday night meetings. Between October 1868 and May 1870, and before it moved to Savile Row in 1870, the RGS's evening lectures were held in the RI where the lantern and screen were much used.[51]

Our knowledge of such pedagogical objects as the lantern is still incomplete: we need to know, in Martin Lawn's words, more 'about why these objects were constructed [and] used within single or integrated systems'.[52] Jeremy Brooker argues that by the 1880s science teachers and students already recognized Tyndall's ingenious model of lantern use.[53] As this article shows, geographers and geography teachers were among the latter.

Tyndall, Mackinder and the lantern

Scholars locate Mackinder's 'lifelong love' of geography in his childhood.[54] However, Mackinder described an influential personal meeting between himself and Tyndall in an early period of his life:

> When a boy I was once stranded at School during the Easter holidays because of measles at home, and happened to see in a newspaper that professor Tyndall was to lecture at the Royal Institution. In my form we had been reading his pellucid lectures on 'Heat as a mode of Motion', so I wrote to him and explained that I was a Schoolboy [*sic*] and short of pocket money, but that he was my hero. By the next post I received a ticket Gratis [*sic*]. I went to the Head, got leave for Town, and heard Tyndall lecture on 'Fluorescence' and saw some beautiful experiments. I went up to the Great man to thank him and he spoke to me kindly. Afterwards I won a scholarship in Natural Science at Christ Church, Oxford. That was my beginning.[55]

49 Deyoung, op. cit. (3), p. 3.

50 Robert A. Stafford, *Scientist of Empire: Sir Roderick Murchison, Scientific Exploration and Victorian Imperialism*, Cambridge: Cambridge University Press, 1989.

51 Hugh Robert Mill, *The Record of the Royal Geographical Society 1830–1930*, London: the Royal Geographical Society, 79–80; Royal Institution Archives Manager's Minutes 1853–1874, vols. 11–12, p. 275; Royal Institution Archives Manager's Minutes 1853–1874, vols. 11–12, p. 311; Roderick I. Murchison, 'Address to the Royal Geographical Society', *Journal of the Royal Geographical Society of London* (1869) 39, pp. cxxxv–cxciv, cxxxvi; Murchison, 'Address to the Royal Geographical Society', *Journal of the Royal Geographical Society of London* (1870) 40, pp. cxxxiii–clxxviii, cxxxiii.

52 Martin Lawn, 'Designing teaching: the classroom as technology', in Grosvenor, Lawn and Rousmaniere, *Silences and Images*, op. cit. (11), pp. 65–82, 69.

53 Brooker, op. cit. (39), p. 126.

54 Parker, op. cit. (17), pp. 259–260.

55 H. Mackinder, unnumbered, notes on scrap, 'Odd scraps of paper found with writing by H.J.M. on them', subfolder Oxford, BLSG, Box 88; Parker, op. cit. (17), p. 2.

Although such testimonies require cautious interpretation, they may nevertheless offer insights.[56] Even if a retrospective construction, it still tells us something about the way Mackinder wished to present his field. Mackinder here describes one of Tyndall's RI lectures on 'Fluorescence' on the emission of ultraviolet light, or nonvisual waves that compel substances to emit slow vibrations invisible to the naked human eye, a subtopic of Lecture Five of Tyndall's *Six Lectures on Light*. The aim of this widely illustrated publication was 'to develope [*sic*] and deepen sympathy between science and the world outside of science. I agreed with thoughtful men who deemed it good for neither world to be isolated from the other, or unsympathetic towards the other'.[57] The lantern was integral to the achievement of these aims.

Tyndall and Mackinder also shared a common connection to mechanics' institutes. Tellingly, the philosopher Thomas Carlyle (1795–1881) described the RI as 'a kind of sublime Mechanics' Institute for the upper classes'.[58] When not working as a surveyor on the railway network, the young Tyndall studied at the Preston Mechanics' Institute.[59] Similarly, the Gainsborough Mechanics' Institute library galvanized Mackinder's childhood imagination.[60]

Mackinder's interest in light-conducting technologies was manifest from an early age. He argued successfully for the installation of electric light at the Oxford Union Society.[61] The subject of his first lecture to the university was electric light, given in 1863 to the Junior Science Club, of which he was a founding member, and which he 'illustrated by numerous diagrams and by a Pilsen arc lamp'.[62] Modelling his own demonstration methods on those of Tyndall, the lantern later became central to his lectures.

Education and educational reform were Mackinder's great passion.[63] In 1886 the syllabus of the Oxford University Extension scheme (OUE) lectures to working-class audiences expanded to include geography.[64] Travelling extensively on the railways that Tyndall helped to survey, Mackinder reputedly delivered some six hundred OUE

56 Kristof Dams, Marc Depaepe and Frank Simon, 'Sneaking into school: classroom history at work', in Grosvenor, Lawn and Rousmaniere, *Silences and Images*, op. cit. (11), pp. 15–46, 28.

57 John Tyndall, *Six Lectures on Light Delivered in America 1872–73*, 2nd edn, London: Longmans, Green and Co., 1875, 1–2.

58 Thomas Carlyle quoted in Jan Golinski, *Science as Public Culture*, Cambridge: Cambridge University Press, 1999, p. 194; in Deyoung, op. cit. (3), p. 15.

59 Joe D. Burchfield, 'John Tyndall: a biographical sketch', in N.D. McMillan and J. Meehan, *John Tyndall: 'X'emplar of Scientific and Technological Education* (ed. P. Hogan), Dublin: NCEA Publications, 1980, 1; in Stephen S. Kim, *John Tyndall's Transcendental Materialism and the Conflict between Religion and Science in Victorian England*, New York, Ontario and Lampeter: The Edwin Mellen Press, p. 1996, p. 28; Ruth Barton, '"Huxley, Lubbock, and half a dozen others": professionals and gentlemen in the formation of the X Club, 1851–1864', *Isis* (1998) 89, pp. 410–444, 417.

60 Blouet, op. cit. (1), p. 13.

61 Blouet, op. cit. (1), p. 22.

62 P.J. Rowlinson, 'Student participation in science teaching: the early years of the Oxford University Junior Scientific Club', *Oxford Review of Education* (1983) 9, pp. 133–136; OU Junior Scientific Club Minutes, 18 November 1882–Friday 7 November 1890, Oxford University Scientific Society Minute Books, Box 8, Bodleian Library.

63 Ó Tuathail, op. cit. (24), p. 113.

64 Parker, op. cit. (17), p. 6; David Phillips, 'Michael Sadler and comparative education, the university and public education: the contribution of Oxford', *Oxford Review of Education* (2006) 32, pp. 39–54.

lectures, many on natural science and economic history, often in mechanics' institutes, and to audiences of elementary teachers.[65] In these lectures, Denis Cosgrove suggested, Mackinder was 'framing the argument' of his 'On the scope and methods of geography' lecture.[66] Critically, from February 1886, his lectures included 'oxy-hydrogen' lantern projections.[67] As a user of the institutes, and lantern lecturer, Mackinder's career paralleled that of Tyndall. Significantly, Mackinder himself employed this optical device in the visual and verbal manifesto that shortly preceded his appointment as reader in Geography at Oxford. In 'On the scope and methods of geography', delivered to an RGS audience in 1887, Mackinder conjured up a vision of a 'new' geography concerned with human–environment relations.[68] Among other things it assessed how artificial lighting had improved life in St Petersburg.[69]

Throughout the 1890s geography school teaching was in the early stages of professionalization. Continuing eighteenth-century teaching practices, the Geographical Association (GA) for teachers, the RGS, the Manchester Geographical Society and the geographer Andrew Herbertson (1865–1915) promoted secondary-school geography by emphasizing the discipline's scientific aspects and rational utility.[70] Soon after, the Education Act of 1902 reorganized secondary-education curricula and staffing. Local education authorities created more school places for girls, thereby generating a demand for teachers. This shift also engendered a need for geography teaching materials. As Mackinder explained his own pedagogy he naturalized the use of an instrument that had once been perceived as contentious by senior RGS figures.[71]

Mackinder's commitment to geography education illuminates his pedagogical philosophy.[72] In his 1906 Presidential Lecture to the Froebel Society, which promoted kindergarten teaching methods, he shared an anecdote which demonstrates the importance of Tyndall in his thought:

65 Gerry Kearns, 'Halford John Mackinder 1861–1947', *Geographers' Biobibliographical Studies* (1985) 9, pp. 71–86, 71; Gilbert, op. cit. (16), p. 28.

66 Denis Cosgrove, *Geography and Vision: Seeing, Imagining and Representing the World*, London: I.B. Tauris, 2012, 125.

67 'Oxford University Extension Lectures', *Lincolnshire Chronicle*, Tuesday 9 February 1886, p. 2, British Library Newspaper archive, at www.britishnewspaperarchive.co.uk, accessed 19 November 2015.

68 Halford Mackinder, 'On the scope and methods of geography', *Proceedings of the RGS and Monthly Record of Geography* (1887) 9, pp. 141–174; Emily Hayes, 'Geographical light: the magic lantern, the reform of the Royal Geographical Society and the professionalization of geography *c*.1885–1894', *Journal of Historical Geography* (2018) 62, pp. 24–36.

69 Mackinder, op. cit. (68), p. 157.

70 Chenxi Tang, *The Reorganization of Geographic Knowledge around 1800*, Stanford: DOI: 10.11126/stanford/9780804758390.001.0001, [2008] 2013, p. 17, accessed 20 May 2019; Andrew John Herbertson, 'On the importance of geography in secondary education, and the training of teachers therein' (1890), pp. 1–5; BAAS Report, 'The position of geography in the education system of the country' (1897), pp. 370–409.

71 RGS, 'Suggestions for drawing up syllabuses of instruction in geography in elementary schools' (1903), pp. 1–12.

72 RGS, 'Report on the teaching of applied geography' (1899); H.J. Mackinder, 'Suggestions for drawing up syllabuses of instruction in geography in elementary schools' (1903), pp. 1–4.

> I have often quoted what I once read in a book of Tyndall's, and I quote it again. Tyndall was the pupil of Faraday, and Tyndall as a young man was going to show Faraday an experiment, and Faraday stopped him, and he said: 'Tell me what I am going to see,' He wished to know what to look for.[73]

Faraday instructed Tyndall to explain experimental processes in order to discipline audience attentions, foster understanding, and thus assert knowledge claims. Like Tyndall, Mackinder emulated Faraday's method. Believing that 'the child is interested in persons, and that history should begin with Heroes' (*sic*), Mackinder included this vignette about his own heroes in *The Teaching of Geography & History*.[74] Demonstration and directed observation alone did not inform or teach; it was necessary to deliver a verbal explanation in order to guide audiences through the processes to which they were witness.

The above passage confirms Brooker's findings by showing 'the importance of attracting and disciplining the eyes and ears of his audiences'.[75] Faraday's attention might otherwise 'have been diverted to immaterial happenings'.[76]

The passage also evidences the continuation of an eighteenth-century tradition of incorporating fictional audiences into science teaching textbooks in order to show the utility of demonstration and to engage readers' imaginations.[77] That period also saw the development of an educational philosophy of associationism, which projected relationships between the acts of inscription, the shaping of the mind of the child, and the latter's conduct in the world.[78] Well-defined educational credentials were a distinguishing feature of, and critical to, the professionalization of nineteenth-century sciences.[79] Mackinder repeatedly name-checked Tyndall and Faraday rather than Huxley, who was also an educational reformer.[80] In doing so Mackinder projected a relationship between himself and the RI's natural philosophers, and constructed his own disciplinary practice around theirs. His presentation of these grandees as mentors, and his use of methods attested to by them, suggest that he sought to mould a new generation of geography teachers in Tyndall and Faraday's likeness.

73 H. Mackinder, 'The teaching of geography to young children', *Child Life* (1906) 31(8), pp. 114–123, 119.

74 Mackinder, op. cit. (12), p. 110.

75 Finnegan, op. cit. (9), p. 5.

76 Mackinder, op. cit. (12), p. 21.

77 Pete Langman, 'The audience is listening: reading writing about learning by doing', in Peter Heering and Roland Wittje (eds.), *Learning by Doing: Experiments and Instruments in the History of Science Teaching*, Stuttgart: Franz Steiner Verlag, 2011, pp. 31–54, 34, 37, 48.

78 Matthew Daniel Eddy, 'The shape of knowledge: children and the visual culture of literacy and numeracy', *Science in Context* (2013) 26, pp. 215–245, 222–224.

79 David Cahan, 'Institutions and communities', in Cahan, op. cit. (7), pp. 291–328, 297; Theodore M. Porter, 'The social sciences', in ibid., pp. 254–290, 258.

80 Paul White, 'Ministers of culture: Arnold, Huxley and liberal Anglican reform of learning', *History of Science* (2005) 43, pp. 115–133, 118.

Natural philosophy, physics and geography

During the nineteenth century, natural philosophy gradually gave way to more specialized sciences.[81] Between 1830 and 1860 professional academic physics became institutionalized in universities as science, and scientific practices diverged from philosophy, theology and other genres of knowledge.[82]

Conceding that a shift in scientific focus and in hierarchies of knowledge had occurred, Mackinder explained that in the 1880s scientific interest lay 'in the accumulating proof of the theory of evolution just as to-day it is in the physics of the Atom [*sic*]'. Despite specializing in animal morphology, Mackinder later observed that it 'was very little applicable to utilitarian purposes' in the 1880s.[83] Mackinder's retrospective attentiveness to physics confirms the assertion that atomic thinking and the recognition of micro-entities as 'the fundamental building-blocks making up the world' shifted in the 1890s.[84]

Huxley, a close friend and colleague of Tyndall, delivered and published numerous public lectures on physiography.[85] When Mackinder and the RGS sought the public recognition of geography, a physiographical approach was powerfully appealing.[86] During his first OUE lectures to working-class audiences, Mackinder essentially taught physiography.[87] In his 1887 BAAS address Mackinder explained the curriculum of his first year:

> It is impossible to teach rational geography without postulation on elementary but sound knowledge of certain chemical and physical laws and facts, chiefly relating to air and water … But physiography is not geography; it lacks the topography, which is the essential element in geography.[88]

Mackinder's claim that his best students had, as he did, a grounding in 'general sciences' rather than history is testament to the foundation of the 'new' geography upon physical sciences.[89] Physiography became the mainstay of his early readership teaching.[90]

Tyndall and Huxley alike were champions of the moral and intellectual, as well as the practical, value of science education.[91] In an 1854 RI lecture Tyndall stated that physics

81 Cahan op. cit. (19), p. 5; Buchwald and Hong, op. cit. (7), pp. 167–174.

82 Cahan, op. cit. (19), p. 9.

83 [H. Mackinder], unnumbered typed autobiographical fragments in MP/C/100 envelope, BLSG, Box 89.

84 Buchwald and Hong, op. cit. (7), p. 193.

85 Paul White, *Thomas Huxley: Making the 'Man of Science'*, Cambridge: Cambridge University Press, 2003.

86 Stoddart, 'That Victorian science', op. cit. (2), p. 26.

87 Blouet op. cit. (1), p. 42.

88 H.J. Mackinder, 'The teaching of geography at the universities, proceedings of the Geographical Section of the British Association. Manchester Meeting 1887', *Proceedings of the Royal Geographical Society and Monthly Record of Geography* (1887) 9(11), pp. 689–707, 699–700.

89 H. Mackinder, 'Modern Geography, German and English', *Geographical Journal* (1895) 6(4), pp. 367–379, 379; letter book containing report from the August 1888 issue of the *Proceedings of the Royal Geographical Society*, pp. 531–532, 532, BLSG, Box GE11A.

90 Letter book containing printed text of 'Oxford local examinations. Junior Candidates. Physiography', BLSG, Box GE11, unnumbered page.

91 White, op. cit. (80), pp. 118, 123.

was 'an implement of culture' with which to develop mental faculties.[92] Similarly, in 1894, at the first meeting of the GA designed to exchange teaching practices and materials such as lantern slides, Mackinder echoed Tyndall in enunciating his vision of 'Geography as a Training of the Mind'.[93] A teacher, he later averred, 'conquers nature like an artist by understanding the properties of the material in which he works'.[94] Similarly, physics was, for Tyndall, 'no mere branch of education, but the means of education itself'.[95] For Mackinder, like Tyndall, argued that his subject 'is but a tool'.[96]

Throughout his career, Mackinder's pedagogical language and practices paralleled those of Tyndall. Whether addressing RGS, BAAS or GA audiences, Mackinder spoke and wrote in an accessible language and was consistently empathetic towards learners. In 1904 he acknowledged that 'until lately, we, as a rule, did not put ourselves into the position of the child's expanding mind. We thought from the adult point of view'.[97] Audiences' fashioning of knowledge is thus substantiated.

Mathematization, close dependence upon technologies and a focus on theory transformed physics from the 1880s. Mackinder's core vision, like that of physics, was processual and attentive to the laws of nature.[98] It consisted of interpenetrating dynamic, dimensional spheres:

> We presuppose a knowledge of physiography. We would then start from the idea of a landless globe, and build up a conception of the earth on the analogy of mechanics. First, the laws of Newton are demonstrated in their ideal simplicity on the hypothesis of absolute rigidity … Imagine our globe in a landless condition, composed … of three concentric spheroids – atmosphere, hydrosphere, and lithosphere … Next introduce the third set of world-wide forces – the inclination of the earth's axis to the plane of its orbit and the revolution of the earth round the sun.[99]

In his 1895 Ipswich BAAS address, Mackinder articulated his vision of the ideal geographer in Tyndallian turns of phrase:

> he can visualize the play and the conflict of the fluids over and around the solid forms; he can analyse an environment, the local resultant of world-wide systems; he can picture the movements of communities driven by their past history … acting and reacting on the communities around; he can even visualize the movement of ideas and words as they are carried along the lines of least resistance.[100]

92 McMillan and Meehan, op. cit. (59), p. 42.

93 B.B. Dickinson, 'Reminiscences', *Geography* (1931) 16, pp. 1–10, 7.

94 H.J. Mackinder, 'The content of philosophical geography', Presidential Address, *Section D (Human Geography), Report, Proceedings International Geographical Congress (Cambridge, 1928)*, Cambridge: Cambridge University Press, 1930, p. 8; in Parker, op. cit. (17), p. 122.

95 William Brock, 'Afterword', in McMillan and Meehan, op. cit. (59), p. 118.

96 Mackinder, op. cit. (12), p. 5; Gillian Beer, *Open Fields: Science in Cultural Encounter*, Oxford: Oxford University Press, 1996, 312–313.

97 H.J. Mackinder, 'The development of geographical teaching out of nature study', *Geographical Teacher* (1904) 2(5), pp. 191–197, 191.

98 H. J. Mackinder P.C., 'The human habitat', *Scottish Geographical Magazine* (1931) 47(6), pp. 321–335.

99 Mackinder, op. cit. (68), p. 155.

100 Mackinder, op. cit. (89), p. 376.

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From 1905 he portrayed geography as 'a branch of physics' distinct from history.[101] In *The Teaching of Geography and History* he asserted,

> Physical geography is in large measure a department of physics, and every teacher should make himself familiar with the great physical principles governing the behaviour of air and water under different conditions … both specific heat and latent heat are involved … though these terms must not be mentioned to the children.[102]

Consequently, geography teachers, especially those whose training had been literary, should purchase a 'primer' of the physics of the air and water.[103] The Scottish meteorologist and geographer Hugh Robert Mill (1861–1950) concurred with Mackinder by asserting that geography 'as a science is so far akin to physics that it is a generalisation of the second order'.[104]

Mackinder expressed his dynamic model of geography as

> the life of animals and plants through the year, from seed to flower and back to seed [and] what Professor Gregory, of Glasgow, has described as 'the fundamental geographical process' – the circulation of water from the sea to the cloud, and back over the land into the sea.[105]

Familiar images such as the flow of ice and a steaming kettle illustrated the transformations within the circuit of water.[106] In turn, the latter illuminated the flow of blood in human physiology.[107] Geographical teaching therefore circulated metaphors, and transposed knowledge, between human and physical sciences.

Inspired by notions of exchange and integration Mackinder thought dynamically and in the round. Geography engendered 'not merely sight … but insight'.[108] Writing in 1935, he claimed that the notionally prophetic skills of the geographer would eventually 'forecast the kaleidoscopic changes of seasonal pattern on the world's surface'.[109] Temporal and spatial relations in their potential past, present and future states fell within the remit of his geography.

Imagery related to energy, inertia and momentum illustrated Mackinder's interdisciplinary outlook.[110] The political and social spheres of human activity were 'the product not only of environment but also of the momentum acquired in the past'.[111] He

101 Halford J. Mackinder, letter to *The Times*, 9 February 1905; in Parker, op. cit. (17), p. 97.

102 Mackinder, op. cit. (12), p. 74.

103 Mackinder, op. cit. (12), p. 74.

104 H.R. Mill, *Geography as a Science in England* (reprinted from *Knowledge*, January 1896), London: Knowledge Office, 1896, pp. 1–12, 2.

105 Mackinder, op. cit. (12), p. 16; P. Bishop and B.E. Leake, 'The beginnings of geography teaching and research in the University of Glasgow: the impact of J.W. Gregory', *Scottish Geographical Journal* (2009) 125 (3–4), pp. 273–284.

106 Mackinder, op. cit. (12), p. 20.

107 Mackinder, op. cit. (12), p. 21.

108 Mackinder, op. cit. (98), p. 328.

109 Halford Mackinder, 'Progress of geography in the field and in the study during the reign of His Majesty King George the Fifth', *Geographical Journal* (1935) 86(1), pp. 1–12, 5.

110 H.J. Mackinder M.A., 'The physical basis of political geography', *Scottish Geographical Magazine* (1890) 6(2), pp. 78–84, 80.

111 Mackinder, op. cit. (68), p. 157.

advanced that 'the principle of momentum or inertia is so called by analogy with the same principle in mechanics. Newton's "first Law of Motion" is to the effect that a moving body tends to continue in movement with the same velocity and in the same direction'.[112] He continued to express the central concept of circulation in terms of the momentum and energy of the hydrospheric 'closed dynamic system'.[113]

At the 1931 BAAS centenary meeting Mackinder described the hydrosphere's 'internal elasticity … fortunately mitigated by the rising and falling of the liquid surfaces and the passage of the liquid into gaseous and solid states' in oceans, air, clouds, rain or snow, and glaciers.[114] His depiction of water as 'the most important and generally diffused agent in the physical processes, both inanimate and animate, at work on the planetary surface' reads like the practical and topographical application of the phenomena investigated by Tyndall.[115]

The lantern was critical to Tyndall's pedagogy. However, light also constituted a source of imagery: 'material Nature furnishes a screen against which the human spirit projects its own image, and thus becomes capable self-inspection'.[116] Mackinder advised the use of newly available light technologies for teaching the angular division of a circle. In 1914 he recommended that 'little electric hand lamps which are now so commonly used for throwing a flash into a dark room or garden' would serve the purpose well by 'cast[ing] a sharply-defined shadow'.[117] An electric lamp or oil lamp globe with the outlines of the continents drawn on in thick black ink projected onto a cone of translucent paper could be employed to 'develop' a map.[118]

Historians of science remain sceptical about the dissemination of scientific knowledge to a wider non-expert community via metaphors, and warn against the conflation of homologues with consequential relationships in the historical material.[119] Metaphor, however, constitutes a key theme around which relativist and realist views of knowledge revolve.[120] The trope of light, already an ancient moral and Christian metaphor, and, from the later nineteenth century, one connected to the emergent moral economies of electricity, featured prominently in Mackinder's speech.[121] In 1890 he declared that geography could be applied 'to the lighting up of history'.[122] In his final years he

112 Mackinder, op. cit. (12), p. 81.

113 H.J. Mackinder, 'The content of philosophical geography', Presidential Address to Section D (Human Geography), *Report of the Proceedings of the International Geographical Congress* (Cambridge, 1928), Cambridge: Cambridge University Press, 1930, pp. 305–311, 310.

114 Mackinder, op. cit. (98), p. 328.

115 H. Mackinder, 'Geography, an art and a philosophy', *Geography* (1942) 27(4), pp. 122–130, 123.

116 John Tyndall, 'On the importance of the study of physics', in Edward L. Youmans (ed.), *Modern Culture: It's True Aims and Requirements. A Series of Addresses and Arguments on the Claims of Scientific Education by Professors Tyndall, Etc.*, London: MacMillan Co., 1867, pp. 1–29, 18.

117 Graeme Gooday, *Domesticating Electricity: Technology, Uncertainty and Gender, 1880–1914*, Abingdon: Routledge, 2016 (first published 2008); Mackinder, op. cit. (12), p. 124.

118 Mackinder, op. cit. (12), p. 125.

119 Buchwald and Hong, op. cit. (7),194.

120 David N. Livingstone, *The Geographical Tradition*, Oxford: Blackwell Publishers, 1992, 18–21.

121 Graeme J.N. Gooday, *The Morals of Measurement: Accuracy, Irony, and Trust in Late Victorian Electrical Practice*, Cambridge: Cambridge University Press, 2004, pp. 23–27.

122 Mackinder, op. cit. (110), p. 79.

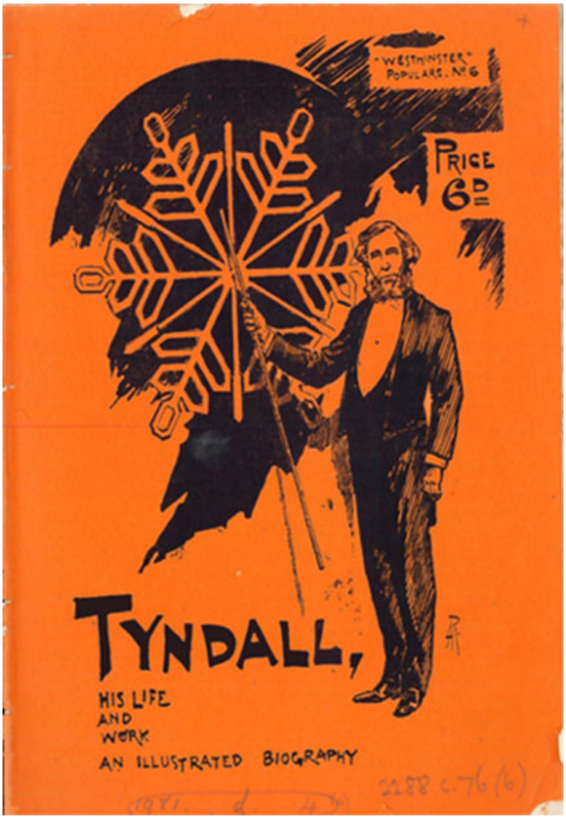

Figure 2. [A.R.], cover image of John Tyndall lecturing before a lantern projection. From *Tyndall, His Life and Work: An Illustrated Biography*, London: 'Westminster' Populars Gazette no 6, 1893.

began to theorize a 'photosphere' and a philosophical scale of geography that encompassed 'The spheres, 5 & 1, Litho-, Atmo-, Hydro-, Photo- (or Radio) Bio-, and a bit apart, Psycho [*sic*]'.[123] His published lecture contained no elaboration of this scheme, but it is significant that he projected these physics-inspired metaphors onto the three-dimensional earth.[124]

The lantern and the imaginative practice of science

Throughout the nineteenth century, scientific practitioners and other intellectuals debated the legacy of romanticism and definitions of the imagination.[125] The 'origin

123 [H. Mackinder], unnumbered, undated sheet, manuscript blue ink, M.P./K/100 envelope, BLSG, Box 88; Rex Walford, 'Mackinder, the GA in wartime and the national curriculum', *Geography* (1993) 78(2), pp. 117–123, 119.

124 Mackinder, 'The music of the spheres', op. cit. (25).

125 Michael Sprinker, 'Ruskin on the imagination', *Studies in Romanticism*, *Victorian Romanticism II* (1979) 18(1), pp. 115–139.

and scope of physical theories', Tyndall ventured, lay in the imagination.[126] The latter comprised 'the mightiest instrument of the physical discoverer'.[127] Tyndall's claim is seen as 'a rejection of positivist empiricism and a reflection of the romantic idealist emphasis on the creative power of the mind'.[128] In theoretical speculations, the imagination became a valid replacement for mathematics. In his 1870 BAAS lecture, Tyndall argued that the imagination could 'dissipate the repugnance, and indeed terror, which in many minds are associated with the thought that science has abolished the mystery of man's relation to the universe'.[129] The 'power of forming *mental images* of the ultra-sensible' informed the German understanding of 'the basis of theory formation in science'.[130]

The juxtaposition of Mackinder and Tyndall's writings and knowledge-making practices reveals how intellectual training alone did not forge the 'new' geography: as Brian Blouet recognizes, Mackinder's 'strongest mental attributes were vision and imagination'.[131] That vivid imaginative faculty animated the essays he had written at school: 'The observation, the reason, the judgment, and the imagination have equal scope, and each must be supported and limited by the others. No expensive apparatus nor tedious mathematical preparation are necessary to commence its study'. Yet his branch of knowledge was no mere 'educational instrument'.[132] Both men saw 'the dynamic interconnections between forces in the physical environment'.[133] However, since it required little preparation and few appliances, and was best pursued as observation in the field, geography differed at this time from Tyndall's laboratory and lecture theatre physics.

Following the publication of 'On the scope and methods of geography', visual methods became a principle of Mackinder's practice. The ideal geographer was 'a man of trained imagination, more especially with the power of visualizing forms and movements in space of three dimensions – a power difficult of attainment, if we are to judge by the frequent use of telluria and models'.[134] Querying the rigid linearity of an earlier pedagogical tradition based on Euclidean geometry, Mackinder warned against the overuse of books and materials that resulted in the stifling of intellectual freedom

126 Tyndall, op. cit. (12), pp. 42–43; in McCabe, op. cit. (42), p. 188.

127 John Tyndall, *Scientific Use of the Imagination*, 3rd edn, London, 1872, 6, in Raychel A. Haugrud, 'Tyndall's interest in Emerson', *American Literature* (1970) 41, pp. 507–517, 515; Howard, op. cit. (44), p. 747.

128 Ruth Barton, 'John Tyndall, pantheist: a rereading of the Belfast address', *Osiris* (1987) 3, pp. 111–134, 122.

129 McCabe, op. cit. (42), p. 208.

130 Barton, op. cit. (128), p. 118; John Tyndall, 'Scientific use of the imagination' (1870), in Tyndall, *Fragments of Science: A Series of Detached Essays, Addresses and Reviews*, 5th edn, London, 1876, p. 426; in M. Yamalidou, 'John Tyndall, the rhetorician of molecularity. Part one. Crossing the boundary towards the invisible', *Notes and Records of the Royal Society of London* (1999) 53, pp. 231–242, 233–234, Yamalidou''s emphasis.

131 Blouet, op. cit. (1), pp. 42–43.

132 Mackinder, 'Geological Epsom', op. cit. (15)

133 Blouet, op. cit. (1), p. 42.

134 Mackinder, op. cit. (89), p. 376.

and in boredom for teachers and students alike.[135] He mused in 1931 that he 'went to school and came under the routine with which our race seeks to make its men dependable and calculable in the tiger hunts of life. But do we not also often dock the imagination with which we come into life?'[136] Thus Mackinder underscored his faith in the imagination.

Good teaching comprised 'the picturing of absent things and movements, some absent in space and some in time, but most in both'.[137] Geography, rightly understood, 'expands and précises a natural power: the power of thinking in the geographical plane'.[138] The teacher's mission was to install the power of 'insight' as '[c]onstructive genius lies in the child-like power of seeing "what is not" continued without break from "what is", or, in other words, of piercing through the material into the immaterial world to perceive the invisible'.[139] To access matter's latent potential, students learned the 'seeing into things and not merely the seeing of things'.[140] Veering into abstraction, Mackinder declared, 'Having now lifted the imagination to the reality, take care to keep the mind concentrated on the real great globe'.[141] In this way the earth was reconceived as a simulacrum of the globe.

In *Six Lectures on Light* Tyndall explained that experiments had two great uses in discovery and verification, and in tuition: 'They were long ago defined as the investigator's language to Nature, to which she sends intelligible replies … after the discoverer comes the teacher, whose function it is to exalt and modify the experiments of his predecessor as to render them fit for public presentation', yet he was branded 'flamboyant' for combining 'practised showmanship with extravagant experiment'.[142] Similarly, there was something of the 'showman' about Mackinder.[143] He was aware of a demand for 'more concrete life in teaching' from audiences of all ages. Demonstrations and thought experiments were essential in conveying the 'visual way of thinking'.[144] Local climatic contrasts should 'live' in pupils' minds with assistance from the science master 'teaching physics in the laboratory'.[145] This faith in live performance motivated his attempts to found a national theatre in 1913.[146] He articulated the perhaps surprising connection between science and drama thus: 'In science, long ago, you had the student turned to the laboratory, and away from the mere book. So it should be in literature. After all a composition was originally intended to be delivered, even poetry, certainly the

135 Mackinder, op. cit. (12), p. 44.

136 Halford Mackinder, typed speech, 13 May 1931, p. 2, [BLSG], Box 89.

137 Mackinder, op. cit. (12), p. 3.

138 Mackinder, op. cit. (97), p. 192.

139 Mackinder, op. cit. (12), p. 2.

140 Mackinder, op. cit. (12), p. 17.

141 Mackinder, op. cit. (12), p. 36.

142 Tyndall, op. cit. (57), p. 3; Howard, op. cit. (44), p. 746.

143 RGS, Hugh Robert Mill Collection, Box 3/Freshfield, from Douglas Freshfield to Hugh Robert Mill, 2 February 1932, 2.

144 H.J. Mackinder, House of Commons, 23 April 1914, National Theatre in London speech, Halford Mackinder LSE archives, Folder M656 Coll., Misc. 482, p. 4; Mackinder, op. cit. (115), pp. 122, 124.

145 H.J. Mackinder, 'Geography in education', *Geographical Teacher* (1903) 2(3), pp. 95–101, 100.

146 Mackinder, op. cit. (144) (1914), p. 3.

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drama'. Ultimately, Mackinder attributed the establishment of geography, and the rise of scientific authority, less to universities than to audiences' thirst for knowledge.[147]

Imaginative practices had featured in geography from the 1860s.[148] Yet Mackinder cited Tyndall and Faraday rather than practitioners and popularizers of geography.[149] Tyndall drew on romantic poets' faith in the imagination as the primary source of creative synthesis. In calling upon audiences' imaginative engagement, he and Mackinder acknowledged the active role of the former in defining the teaching and learning process; both valorized subjective understandings at a time when objectivity featured in disciplinary discourses, and the creation of objectivity was nurtured via the harnessing of visual supports and media.

Imaginative practices were activated with the internal instrument of the mind's eye.[150] In urging them 'to "look with the mind's eye" at oscillating atoms' Tyndall trusted audiences' own imaginative knowledge-making abilities.[151] In his RI Christmas lecture 'The forms of water in clouds and rivers, ice and glaciers' he exhorted his audience to '[i]magine the molecules of water in calm cold air to be gifted with poles of this description, which compel the particles to lay themselves together in a definite order'. Thus they would reveal 'the unseen architecture' of nature.[152]

Mackinder, similarly, advocated the cultivation of a 'sympathetic imagination' by retaining the 'childish power of thinking in images' with 'the mind's eye'.[153] Before showing students images, teachers should visualize

> the tips of the glaciers breaking away and floating off as icebergs … Let them imagine the passing away of the ice-age again, and let them bring the sea back into the lower glens so as to form sea-lochs, straits, peninsulas and islands.[154]

Geographical features and, by extension, historical human activities such as the march of armies across time and space could be envisioned. He favoured such expressions until the end of his life.[155]

147 Mackinder, op. cit. (144) (1914), p. 4.

148 J.N.L. Baker, 'Mary Somerville and geography in England', *Geographical Journal* (1948) 111, pp. 207–222, 219.

149 Mary Somerville, *Physical Geography*, 2 vols., London: John Murray, 1848, 299; Huxley, op. cit. (20).

150 The 'mind's eye' originates from *acies mentis* ('gaze of the mind') and its Greek equivalent. A. Fitzgerald, J.C. Cavadini and M. Djuth (eds.), *Augustine through the Ages: An Encyclopedia*, Grand Rapids, MI: William B. Eerdmans Publishing Co., 2009, 5–6; Iwan Rhys Morus, 'Optical illusions fool the eye but they educate the mind (trick of the eye)', 20 January 2014, *Aeon*, at https://aeon.co/essays/optical-illusions-fool-the-eye-but-they-educate-the-mind, accessed 3 October 2017.

151 John Tyndall, 'The physical basis of solar chemistry', in Tyndall, *Fragments of Science: A Series of Detached Essays, Addresses and Reviews*, 2 vols., London: Longmans, Green, and Co., 1879, vol. 1, pp. 381–394, 389. 'Mind's eye' does not feature in Huxley, op. cit. (20).

152 John Tyndall, *The Forms of Water in Clouds & Rivers, Ice & Glaciers*, London: H.S. King and Co., 1872, p. 34; in Frank James (ed.), *Christmas at the Royal Institution*, World Scientific Publishing Company, 2007, p. 57, ProQuest Ebook Central https://ebookcentral.proquest.com/lib/oxford/detail.action?docID=1681218, accessed 3 October 2017.

153 Mackinder, op. cit. (12), pp. 7–8.

154 Mackinder, op. cit. (12), p. 68–69.

155 Mackinder, op. cit. (115), p. 124.

In the construction of imaginary landscapes of science, topographical and geographical terms afforded a language of transference and transformation. Abstract science thinking was spurred by the conception, and expression, of fictional places.[156] Tyndall's mountaineering exploits galvanized his scientific imagination, and his metaphorical repertoire.[157] The use of such expressions enabled audiences and readers to transcend the physical world and the experiments demonstrated to them.[158]

Mackinder's graphic expressions also appealed to 'the mind's ear'.[159] Robert Mayhew has identified the 'congruity between programme and practice' in Mackinder's *Elementary Studies in Geography* series.[160] Sliding spatial scales mediated the movements of thought. In theorizing the brokering of knowledge by oasis-dwelling peoples, Mackinder argued, 'They drew a veil between East and West which heightened the effect of the desert. To borrow a simile from physics, this veil was transparent to things, but not to ideas'.[161] In their imaginative practices, inverted images of the other are therefore seen; Tyndall employed topographical and geographical analogies, whilst Mackinder harnessed metaphors from 'the high priests of science … mathematicians and physicists' to elucidate human transformations across time and space.[162]

For Tyndall the distinction between visible and invisible rays 'did not reflect the nature of things but the limited capacity of human vision'.[163] Tyndall located his own work 'in the shadowy space beyond the red of the visible spectrum', an area of 'darkness which surrounds the world of the senses' where 'the mere signs of external things' were seen with the imperfect organ of the human eye.[164] Audiences ventured 'beyond the boundary of mere observation, into a region where things are intellectually discerned'.[165]

Vision is a core geographical skill. Mackinder's geographical philosophy evidences his concern with dynamic processes of interaction and exchange between visible and invisible matter. Travelling into 'imaginative space', teachers became path-finding guides leading students into landscapes of knowledge.[166] Geography was theorized as six roads: drawing and modelling, nature study, the annual flow and ebb of animal and vegetable life, the circulation of water, romantic tales of distant lands, and 'once upon

156 Alice Jenkins, 'Spatial imagery in nineteenth-century representations of science: Faraday and Tyndall', in Crosbie Smith and Jon Agar (eds.), *Making Space for Science*, Basingstoke: MacMillan, 1998, pp. 181–191, 181.

157 Michael Reidy, 'Evolutionary naturalism on high: the Victorians sequester the Alps', in Gowan Dawson and Bernard Lightman (eds.), *Victorian Scientific Naturalism: Community, Identity, Continuity*, Chicago and London: The University of Chicago Press, 2014, pp. 55–78.

158 John Tyndall, *Forms of Water in Clouds and Rivers, Ice and Glaciers*, 4th edn, New York: D. Appleton, 1897, p. 52; Haugrud, op. cit. (127), pp. 514.

159 Mackinder, op. cit. (115), p. 124.

160 Mayhew, op. cit. (28), p. 787.

161 Mackinder, op. cit. (110), p. 82.

162 Mackinder, 'The music of the spheres', op. cit. (25), p. 175.

163 Yamalidou, op. cit. (130), p. 232.

164 Tyndall, op. cit. (130), p. 43; in Yamalidou, op. cit. (130), p. 232; John Tyndall, *Fragments of Science: A Series of Detached Essays, Addresses and Reviews*, 10th impression, 2 vols., London: 1899, 1, p. 193; in Beer, op. cit. (96), p. 305.

165 Tyndall, op. cit. (130), p. 425; in Yamalidou, op. cit. (130), p. 233.

166 Mackinder, op. cit. (12), p. 39; Jenkins, op. cit. (156), p. 186.

a time'. The latter led to the sphere of physics and 'to the conclusion that the earth is a body hung in space'.[167]

Both men employed metaphors from the integrated and multi-scalar perception of natural phenomena that was central to physics.[168] Mental projection animated and transported phenomena: 'Now philosophers may be right in affirming that we cannot transcend experience. But we can at all events, carry it a long way from its origin', declared Tyndall.[169] Articulating the cosmological via familiar examples, he made visible and audible 'the reaches of vibration that make up life'.[170] Tyndall performed 'imaginative mental leaps', and in order to explain natural processes he rescaled them:[171]

> the magic of its art consists, not in creating things anew, but in so changing the magnitude, position, grouping, and other relations of sensible things, as to render them fit for the requirements of the intellect in the subsensible world.[172]

Like the lantern, mental projection exposed the latent properties or processes of phenomena by magnification. Rendering phenomena visible brought them into existence:

> Thus our first notions and conceptions of poles are obtained from the sight of our eyes in looking at the effects of magnetism … we then transfer these notions and conceptions to particles which no eye has ever seen … Without imagination we might have *critical* power, but not *creative* power in science.[173]

Early twentieth-century classrooms have been described as spatially and materially alien environments of 'high whitewashed walls full of crumpled maps, worn-out charts, and other scraps of paper'.[174] Yet for Mackinder they were places in which teachers and pupils could nurture their humanity through imaginative practice. Performing intellectual acrobatics he rescaled concepts, thereby perpetuating the eighteenth-century schooling traditions.[175] 'Above all we lead the imagination to think on the big scale, the world scale, which is essential to powerful thinking in later life', he explained.[176] Whilst Tyndall scaled up the minute or invisible, Mackinder scaled down the world's features to bring the distant close. The lantern and the imagination functioned symbiotically as instruments of visualization which exposed the dynamics of geographical phenomena and demonstrated their equivalence.[177]

167 Mackinder, op. cit. (12), p. 4.

168 Beer, op. cit. (96), p. 248.

169 John Tyndall, 'On the scientific use of the imagination', in Tyndall, *Fragments of Science*, New York: P.F. Collier, n.d., p. 6; in Haugrud, op. cit. (127), p. 515.

170 Beer, op. cit. (96), p. 248.

171 Maria Yamalidou, 'John Tyndall, the rhetorician of molecularity. Part two. Questions put to nature', *Notes and Records of the Royal Society of London* (1999) 53, pp. 319–331, 321; Howard, op. cit. (44), p. 737.

172 John Tyndall, *Six Lectures on Light Delivered in the United States in 1872–1873*, 4th edn, 7th impression, London: Longmans, Green, and Co., 1915 (first published 1873), pp. 42–43; in McCabe, op. cit. (42), p. 188.

173 Tyndall, op. cit. (152), pp. 1–34, original emphasis; in James, op. cit. (152), p. 59.

174 Dams, Depaepe and Simon, op. cit. (56), p. 22.

175 Eddy, op. cit. (78), pp. 238–239.

176 Mackinder, op. cit. (12), p. 36.

177 Mackinder, op. cit. (12), p. 11.

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The science, art and philosophy of geography

Later nineteenth-century scientific naturalists aspired to 'construct a public image of science as a moral and intellectual force'.[178] In doing so their commitment challenged Christian doctrine.[179] As well as performing research, and 'instruction and edification' via dramatic experiments, scientists strove to embody standards of public morality.[180] Scientists were, for Tyndall, qualified to judge all affairs of the natural world.[181] Huxley shared these views.[182]

It is arguable that Tyndall's romantic transcendental physics paralleled religious expression, even whilst apparently repudiating it.[183] His aim was for audiences to transcend the senses to reach a place 'where vision becomes spiritual, where principles are elaborated, and from which the explorer emerges with conceptions and conclusions'.[184] The philosophy and poetry of the American transcendentalist poet Ralph Waldo Emerson (1803–1882) resonate in Tyndall's verses.[185] By using a 'molecular language' as Emerson did, Tyndall elucidated phenomena across multiple scales 'from the level of the imperceptible ether, whose particles vibrate thus transmitting radiant heat and light through space, to the level of "the grass of a meadow", whose molecules impart their vibratory motion to ether thus becoming chilled "on a starlight night"'.[186]

Over time, Mackinder's philosophical turn of mind, already discernible from 1887, became more manifest. From 1890 he saw geography as a philosophy and a science.[187] Further, as with Tyndall, 'imaginative eloquence' transformed him into an interpreter of culture.[188] Because the imaginative spatialization was integral to mathematical and moral training, teachers inculcated an ethics of space.[189] As physics professionalized and specialized, the concerns of a tradition of natural philosophy found expression in geography: 'Geography begins from two poles of our observation, from the home and from the heavens. The one is local and at our feet, the other is universal'.[190] Mackinder incorporated natural philosophy's aims of questioning, interpreting and explaining into an existing geographical tradition of regional description, distinguishing between

178 Thomas William Heyck, *The Transformation of Intellectual Life in Victorian England*, London and New York: Croom Helm and St Martin's Press, 1982; in Deyoung, op. cit. (3), p. 3.

179 Lightman, op. cit. (44); James Secord, *Visions of Science Books and Readers at the Dawn of the Victorian Age*, Oxford: Oxford University Press, 2014, p. 305.

180 Iwan R. Morus, 'Worlds of wonder: sensation and the Victorian scientific performance', *Isis* (2010) 101, pp. 806–816, 811.

181 Deyoung, op. cit. (3), p. 11.

182 Finnegan, op. cit. (9), p. 9.

183 Beer, op. cit. (96), pp. 259–260.

184 John Tyndall, *Heat a Mode of Motion*, 11th edn, reprint of the 1880 6th edn, London: Longmans, Green and Co., 1898, viii; in McCabe, op. cit. (42), p. 184.

185 Tyndall, op. cit. (158), xvii; in Haugrud, op. cit. (127), pp. 509–510; Francis O'Gorman, 'John Tyndall as poet: agnosticism and "A morning on Alp Lusgen"', *Review of English Studies* (August 1997) 48, pp. 353–358; in Yamalidou, op. cit. (130), p. 235.

186 Tyndall, op. cit. (130); in Yamalidou, op. cit. (130), p. 235.

187 Mackinder, op. cit. (110), p. 78.

188 Beer, op. cit. (96), p. 249.

189 Mackinder, op. cit. (12), p. 1; Eddy, op. cit. (78), pp. 238–239.

190 Mackinder, op. cit. (12), p. 28.

scientific researchers and teachers, whom he said 'can and should think of the bearing of science on the art of living; in other words, should think of its relation to moral and aesthetic values'.[191]

References to the numinous resonate throughout Mackinder's publications and lectures. Although his nature mysticism was never ardent, he nevertheless believed in geography's central unifying role within a scientific and humanistic continuum.[192] From 1906 geography became 'an art of expression', and in it the expression 'all flesh is grass' was a recurring refrain:[193]

> All flesh is grass. You feed on vegetables and on the flesh of animals, but the animals in their turn have fed on vegetables. So your life, and all life, is dependent on the sun's light and heat. Even the light that comes from the moon is reflected from the sun. But the stars are distant suns.[194]

This biblical expression illuminated Mackinder's sense of a continuum of energy exchange. In transmitting this physics-derived language, Mackinder amplified rather than diminished the energy of interpenetrating phenomena.[195] His urging of teachers and students alike to transcend static classroom walls was perhaps a manifestation of his spiritual development.

Geography, as Kant perceived it, was a propaedeutic field.[196] In Mackinder's practice, it remained a transcendental discipline which overlapped with other sciences. Its function was to bring to light relations between humanist and scientific education curricula, and the arts and sciences, for sociopolitical purposes.[197] Mackinder argued that in government, and the civil service, 'a rift divides the organization of our higher education [and its effect] has been to press most educated people, including the teachers in our public and secondary schools, into one or other of the two moulds'. The solution was an education which taught the seeing of 'the world whole'.[198]

The 'new' geography's 'inherent breadth and many-sidedness' mirrored Mackinder's political ideology that saw 'culture' as an integrated system which, if threatened with disintegration, might or should exist in a state of natural balance.[199] Here Mackinder's idealistic views differed from those of Tyndall who, in exposing the second law of thermodynamics, rejected equilibrium as a desirable state.[200] Nevertheless, Mackinder later urged

191 Mackinder, op. cit. (109), p. 7.

192 David Matless, 'Nature, the modern and the mystic: tales from early twentieth century geography', *Transactions of the Institute of British Geographers* (1991) 16(3), pp. 272–286.

193 Mackinder, op. cit. (73), p. 117; Walford, op. cit. (123).

194 Mackinder, op. cit. (12), p. 30.

195 Beer, op. cit. (96), p. 207.

196 Charles W.J. Withers, 'Kant's *Geography* in comparative perspective', in Stuart Elden and Eduardo Mendieta (eds.), *Reading Kant's Geography*, Albany, NY: SUNY Press, 2011, pp. 47–65, 52.

197 Guillory, op. cit. (31), pp. 19–44.

198 Halford Mackinder, *Times Educational Supplement*, 7 September 1916, in Parker, op. cit. (17), pp. 92–93; Walford, op. cit. (123), p. 121.

199 Mackinder, op. cit. (68), p. 159; in Ó Tuathail, op. cit. (24), p. 114.

200 Beer, op. cit. (96), pp. 299–300.

geographers to maintain ties with archaeologists and geologists, and intimated his hope that 'in becoming Realists let us not cease from being, in a reasonable degree, Romantics'.[201]

Authors' ideas are frequently inconsistent, change and become fluid through the influence of others and of new interpretations.[202] Mackinder's geography moved further towards philosophy. By 1935 geography comprised the 'natural and appropriate counterpoise for the materialism of the specialist sciences' that Tyndall himself had been instrumental in establishing.[203] He granted that

> apart from certain aspects of its technique, geography is not a science in the sense that physics, chemistry, biology, and even geology are sciences. Nor is it one of the humanities, like history. It is something apart – a concrete philosophy, with both scientific and humanistic roots, though with its own technique both of research and expression.[204]

The subject, he explained to GA teachers in 1942, 'culls its data from the geographical aspect of a number of sciences … integrates its conclusions from the human standpoint, and … departs from the objectivity of science, for it ranges values alongside of measured facts'.[205] Geography became 'the chief outlook subject', as Mackinder aligned his philosophy with the Scottish geographer and sociologist Patrick Geddes's (1854–1932) approach.[206] Embodied symbolically by the camera obscura used in the teaching in Edinburgh's Outlook Tower, the approach apprehended sliding scales of phenomena in order to engender an understanding of the unity of the physical, organic and social conditions.[207] Mackinder's 'philosophy of Man's environment' aspired for geography to become such a beacon.[208]

Conclusion

This essay has argued that Tyndall's natural philosophy and physics demonstrations with the lantern helped fashion the geographical theorization, and visual and imaginative teaching methods, of Mackinder. Natural philosophy did not cease, as the early nineteenth-century historiographers of science investigated by Schaffer argued. Instead its practice was displaced. The 'new' geography was made by, and within the context of, natural-philosophical practices that sometimes coexisted with, and sometimes were gradually superseded by, the emergent discipline of physics. More than that, geography was shaped by particular spaces and practices. Mackinder's connecting of the RI lecture theatre to classrooms shows the construction of geographical authority in certain sites. Consideration of scientific knowledge making in civic and popular spaces is therefore

201 Mackinder, op. cit. (98), p. 335.
202 Withers, op. cit. (196), p. 54.
203 Mackinder, op. cit. (109), p. 10.
204 Mackinder, op. cit. (109), p. 11.
205 Mackinder, op. cit. (115), p. 129.
206 Mayhew, op. cit. (28), p. 780.
207 Patrick Geddes, 'The Edinburgh Outlook Tower', in *Report of the 68th Meeting of the British Association for the Advancement of Science* (Bristol 1898), London: John Murray, 1899, pp. 1–1069, 945–947; C.W.J. Withers, *Geography, Science and National Identity: Scotland since 1520*, Cambridge: Cambridge University Press, 2001, p. 226.
208 Walford, op. cit. (123), p. 121.

essential: non-academic spaces, and the human actors participant in and around them, helped shape disciplinary epistemologies. These diverse popular and non-expert wellsprings engendered the vitality of geography. The same is true of geography's pedagogic practices and its instruments.

While we have studies, such as Finnegan's, of rhetorical practices, this paper has turned to the devices by which audiences were enlightened. The lantern featured in Tyndall's RI performances which resonated with the coming generation of scientific practitioners and popularizers.[209] Mackinder's engagement with the lantern was equally instrumental. Though it was only one element in a greater visual, verbal and physical performance and range of teaching materials, the technology helped structure teacher and student experiences alike. The academic professionalization of the 'new' geography, and its subsequent dissemination and popularization to a diversifying community of teachers and students, were closely connected to the lantern's use.

Tyndall and Mackinder interacted in shared imaginary spaces that were conceived and articulated by common expressions and metaphors. Animated by his recourse to the power of the imagination, verbal agility, and map and image projections, Mackinder made the dynamic interaction of topography and human behaviour visible to diverse audiences in OUE, RGS, Oxford University, BAAS and GA lectures.

The attentiveness to imaginative practice in Mackinder's philosophy of teaching suggests that despite efforts to professionalize geography by establishing the discipline's scientific credentials and by training its educators, there was a cautiousness towards the over-standardization of methods and materials. Science teaching and learning were rather creative enactments. Moreover, despite his detractors' later comments, Mackinder knew some history, geology and climatology. Elements of these fields, animated and integrated by an understanding of physics, significantly shaped his vision of geography. That this is so counters the historiographical narratives of disciplinary specialization in the nineteenth-century sciences identified by Schaffer. Rather, as Staley argues, physics was powerful in shaping a spectrum of human and physical sciences. Physics was as fertile as, and combinable with, the Darwinian theory of natural selection. Mackinder absorbed new physics concepts throughout his life, and incorporated them into his morphing geographical scheme. Shifting individual interests, circulating idioms and images, and the inclusion of new knowledge-making audiences into academic and non-academic institutions resulted in a variegated and metamorphic landscape of knowledge which complicates nineteenth-century disciplinary identities and periodizations.

What emerges, therefore, is Mackinder and Tyndall's multifacetedness. Their practices cannot be equated with those of a single discipline. We must reconsider easy assumptions about individual practitioners of disciplines which are too often conceived as objectively and methodologically distinct. Although Mackinder's intellectual and rhetorical shifts were audience-dependent, physics and Tyndall remained fixed referents. In this important sense, elements of Tyndall's transcendental physics flowed into the professionalizing 'new' geography. Mackinder modelled his vision of a discipline concerned

209 Lightman, op. cit. (44), pp. 10–13.

with human and non-human matter, and the processes that animated these across time and space, upon the materials and phenomena investigated in physical sciences. Mackinder's geographical pedagogy was fashioned by the knowledge of physics reified in lantern technology. Though Mackinder claimed that geography was a branch of physics, what he referred to was closely akin in scope and in methods to natural philosophy. The RI sustained that tradition and Mackinder's composite geography was fashioned in its light.

Finally, Mackinder's encounter with Tyndall shaped the former's perception of the hierarchies of science. Though a non-specialist, Mackinder appropriated the language and idioms of physics for metaphorical purposes and, in doing so, popularized them. The circulation of metaphors and language incurred mutual exchange and disciplinary interpenetration, consequently raising questions about disciplinary identities and their professionalization and periodization. This paper has therefore observed the making of knowledge: histories of disciplinary practice beyond the academy, and beyond scientific practices, show how certain practices were made in and moved between disciplinary contexts. Learning which galvanizes disciplinary methods and theorization occurs in diverse contexts, including in sites of knowledge popularization. This highlights the importance of diverse and popular audiences (amongst whom Mackinder figured), and their creative engagement with science. Even as his geographical philosophy oscillated between idealism and materialism, Mackinder tethered geography to physics and Tyndall.