Colonialism and science

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Abstract. This review will, by examining the available literature, attempt to detail the relationship between scientific development and imperial expansion during the colonial era. It will discuss the various ways in which science was used to justify colonialist and racist attitudes at the time, and it will present two different models of scientific diffusion, examining the strengths and weaknesses of each, and how the perception of this diffusion has led to a Eurocentric viewpoint in science. It will provide an in depth review of non Western science, highlighting the importance of different cultures and epistemologies, and go on to discuss the modern day effects of colonialism on science. Finally, it will examine whether there were any benefits of colonialism in the context of science and use two prominent scientific ethics debates to answer this question.

1. Introduction

The colonial era began in approximately 1500, and lasted well into the end of the 1900s, when decolonisation efforts began to take place, Magdoff (nd.). This era was dominated by Europe, characterised by the large empires spawned from states like Spain, Portugal, France, the UK and the Netherlands. In fact, over the course of this 400 years, only five countries completely escaped European influence, Fisher (2015). The colonial expansion of Europe had its foundations in brutality, not limited to such things as forced removal of indigenous people, separation of families, and in some extreme cases, even genocide, Jalata (2013).

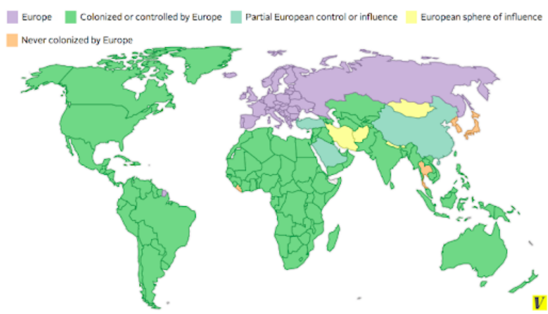

Figure 1. The above diagram shows countries which were under European influence during the colonial era. Note that only five escaped this completely: Liberia, Thailand, Korea, (now North and South), and Japan, Fisher (2015).

The beginning of the colonial period coincided roughly with the renaissance in Europe and as such, from its early days, science was closely linked to the expansion of Europe throughout the world. Colonialism benefited science and it can be argued that it was responsible for many scientific developments. However, science was also used as a tool of imperial expansion, allowing European powers to exert greater control over the rest of the world, and also providing 'empirical' justifications for colonialism, Adas (2016).

The close relationship between science and the spread of European empires, as well as a disregard for any non Western scientific methods has led to a widespread Eurocentric bias within science. As such it is important to recognise the wealth of non European science and how European science has been largely built on the achievements of other cultures, Joseph (1987).

There have also been many wide ranging effects of colonialism on science in today's world, many of them detrimental to developing scientific communities outside the Western world, Fassin (2003). However, it is also important to consider the possibility that colonialism may have had some benefits for science, but these must be analysed within the context of imperialism and not just the empiricism of scientific research.

2. The link between science and colonialism

Throughout the colonial period, science was strongly linked to the expansion of European empires. From the very beginning of this period, when European explorers were first venturing into the wider world, science was present in the fields of navigation, astronomy, and in the development of new instruments. The long voyages necessitated more advanced navigational procedures, and so the scientists who journeyed with the explorers of the early colonial period had to refine their technology to make accurate astronomical observations and more accurate maps, Adas (2016). Adas describes how science was conducted both pre and post industrial revolution. Before the industrial revolution, scientists in the colonies were more concerned with natural history: collecting botanical samples, mapmaking and cartography, and classifying different species of wildlife. However, after the industrial revolution, the focus shifted to fields such as geology, mineralogy, chemistry, and engineering, fields which delivered more concrete benefits to the colonial powers. Harrison (2005) concurs, saying that colonialism was vital to the development of such fields.

2.1. Science as a tool of empire

Many scientific advancements were borne out of colonialism. For example, in the field of transportation, the development of steamboats came from the need to navigate inland rivers in Africa, and early aircraft were used to surveille and attack rebellions in some colonies, Roy (2014), and the development of railways in the 19th century allowed faster inland travel and created a closer link between the colonies and the Western powers, Jedwab et al (2017). In communications, setting up telegraph lines was vital to ensure messages could be sent over large distances and during the Boer wars, the need for rapid communications that were hard to intercept found its realisation in wireless radio, Roy (2014). In medicine, the desire to reduce the spread and lethality of tropical diseases encountered in the colonies meant that many advancements were made in a short period of time Brown (2004). And in engineering, the creation of newer, more lethal weapons was necessary to allow more lands to be conquered and more people to be brought under imperial rule, Bocetta (2017).

However, it was not just that colonialism benefited science. Although the domination of European powers opened up new areas of research and provided insights into new fields of study, the main driving force behind the science conducted in this era was the fact that science could be used to aid in this imperialist expansion. It gave European nations an advantage over cultures which they were attempting to bring under control, Adas (2016), and Arnold (2006) referred to different fields of science as 'tools of empire'. Research into cartography was motivated by the need for an intimate knowledge of the local geography to ensure that imperial troops could push further inland, and advancement in the treatment of tropical diseases was brought about not because of any goodwill towards the people under colonial rule, but to protect the soldiers and agents of colonialism from ill health, Roy (2014).

In fact, the main focus of science in the colonies was to identify and extract natural resources to further the imperialist ideal, Harrison (2005), and Alam (1977) describes this as 'production science', which is the idea that any scientific research conducted in colonised areas was done purely to generate profit and provide natural resources to fuel the empire's industrial needs. Adas (2016) details how fields such as botany and geology were primarily used to inform the colonists about the natural resources a colony contained and the best way to extract them.

Figure 2. "In the coming century, the success of imperialism will depend largely upon success with the microscope"-Sir Ronald Ross, a British doctor who worked extensively in Southeast Asia. This shows that this attitude was widespread at the time, and not just an observation by historians. Image obtained from en.wikipedia.org.

Colonial science could not have been as successful an endeavor if not for the indigenous populations. Adas (2016) describes how crucial the native populations were in helping European explorers gather samples, in particular botanical specimens, finding elusive wildlife and collecting geological samples. Arnold (2006) describes the help of Indian native as 'indispensable', although these natives were rarely credited for their work. This shows the culture of exploitation upon which colonial science was founded, and that although science at that time is seen as a European achievement, it would not have been possible without the help of indigenous people.

Science was also used as a tool to control the local population. Harrison (2005) described how the knowledge of local geography allowed indigenous people to be grouped into areas that were tied to race, and thus allowed the colonists to implement social control, and how careful urban planning allowed for greater control over the populace. Arnold (2000) is in agreement and explains how science was used to gain a deeper understanding of the indigenous population and subsequently to control them. In his book "Colonising the body" (1999), Arnold also describes how the attempts to control outbreaks of diseases like smallpox and cholera led to the colonial government implementing social controls on their subjects, by constricting their movements and even their diets. Adas (2016) talks about the use of science to influence non colonised leaders. In places like China and Japan, even though there was no imperial presence, the British empire still attempted to influence local politics and affairs to suit itself. Science allowed colonial powers to impress and gain access to leaders in Asia, and in this way, these countries could be brought more under the control of the empire, without being formally colonised. Furthermore, in colonies with a large population of non European natives, access to scientific knowledge was made extremely difficult out of concerns over security and economic competition in the future, Adas (2016). In other circumstances, scientific and technological expertise was limited to the European elite, with colonised subjects being denied education in emerging fields, Harrison (2005), fields which would prove critical in the modern world.

2.2. The death of indigenous science

The arrival of European science to other areas of the world had massively detrimental effects on local scientific knowledge and expertise. The influx of European scientists, combined with the utter disregard for any indigenous epistemologies resulted in a decline in native scientific progress, Emeagwali (2008). The scientific domination of Europe over the colonies resulted in indigenous science being seen as redundant, and no effort was made to keep local scientific traditions alive, Alam (1977). In some cases, there were even active attempts to smother local industry. For example in Africa, the continent was saturated with cheap materials from Europe, which resulted in the decline of local production of glass and metal, Emeagwali (2008). Another factor to consider is that any science carried out in the colonies usually took the form of fieldwork, with colonial scientists less involved with research and more with gathering information, Harrison (2005). And specimens or data were shipped back to Europe where the actual analysis and publication of research was done and made available to the European scientific community through scientific societies, Adas (2016). This division between data gathering and scientific analysis created a dependence of the colonies on the European power in terms of scientific development, Villafuerte (2020). The lack of scientific institutions in the colonies meant that they needed to rely on their European coloniser for scientific funding and direction, and it starved these colonised countries of any scientific development that they could call their own.

The implementation of Western science and the near extinction of indigenous science allowed colonists to use scientific education to impose their beliefs on certain groups of indigenous people, Emeagwali (2008), and this led to the creation of a social class of native people who shared the imperial ideology and thus could help further the colonial agenda, Pomeranz (2005).

3. Scientific justification of colonialism and racist attitudes

3.1. The civilising mission

In the colonial era, many people tried to justify the expansion of the empire. One of the main arguments of the time was that of the 'civilising mission', the idea that other cultures were backwards and uncivilised, and that they needed the guiding hand of the empire to become ready to govern themselves, Pomeranz (2005). The indigenous people were seen as living in 'secular backwardness', Villafuerte (2020), and Rudyard Kipling described it as the 'white man's burden' to modernise their culture. However, as Pomeranz notes in his paper "Empire and 'civilising' missions, past and present", if any empire were to claim success in 'civilising' the native population, their mission would be complete and their continued presence as colonisers obsolete. From this it can therefore be seen how the 'civilising mission' was a hollow ideology, pervaded with racist attitudes and simply a way to rationalise the continued expansion of the empire.

Throughout this civilising ideology, science played a crucial role. Science was intrinsically linked to the European desire to civilise and modernise their colonies, Arnold (2000), and Adas

(2016) describes science as 'the linchpin of rationalising offensives' which was used to change the culture and society of indigenous populations into a model which fit the expectations of European colonialists. The huge advancements in European science and technology during the colonial era, in the imperialists minds' at least, elevated European civilisation and implied the inferiority of non Europeans, Roy (2018). Roy also describes how colonialism was justified, as it was claimed that European scientific advances could be used to advance the interests of colonised peoples, in areas such as healthcare and hygiene.

3.2. The history and development of scientific racism

Harrison (2005) stresses that imperialism and the expansion of the empire had a crucial role in the development of scientific racism. This refers to the idea of using scientific observations, usually flawed, to justify racist attitudes and policies, and to allege the superiority of one race (usually European) above all others. Adas (2016) briefly describes the emergence of scientific racism in the early days of colonialism. Ethnologists, who according to Adas usually had no formal training, began to report on the different groups of people they encountered, and the observations they made were used to classify different races. This was an allegedly scientific process but as Adas points out, the classifications were usually hierarchical. This allows us to see the way in which science was used, straight from the beginning of the colonial period, to promote the superiority of the European colonisers and to establish a system of dominance which would last for hundreds of years.

Curtin's 1960 paper '"Scientific" racism and the British theory of empire' provides a comprehensive history of scientific racism, and thus it is a good starting point in the literature to examine this field. In the early days of colonialism, various Biblical arguments were used when debating racism and xenophobia, but it wasn't until the latter half of the 18th century that 'scientific' arguments became popular. This coincided with the period when science began to gain more respect and be taken seriously. Curtin identifies that although many scientific justifications were made, the defining component was skin colour. When scientists attempted to classify and rank human races, there was much debate around the intricacies of this; where certain races should be placed, how distinct they were, and how much separation there should be. However, one aspect that was almost universally agreed upon was that lighter skinned humans were superior, and darker skinned humans inferior. Thus, when European scientists created a scale to classify humans, light skinned Europeans were placed at the top and darker skinned races were ranked lower.

This is an important point to note, as it clearly shows a blatant racist agenda at the heart of science in the colonial era. While scientists were perfectly happy to argue about their methods, it was taken for granted that white Europeans were superior, and there is no evidence of any consideration that this should not be the case.

Curtin then proceeds to highlight the emergence of evolutionary racists. While earlier views held that white Europeans were superior simply because this was the natural order of things, some began to contend that the classification of races was not constant, and that due to evolution, one particular race could become superior than another. This position was characterised by the view that weaker races would slowly die out and give way to stronger races, and so the different races of humans were in effect competing with one another. This ideology was implemented in the British empire's native policy in settler colonies, where there were many European immigrants, and a population of indigenous people. The expansion of the empire coincided with decline in population of the indigenous people, and some people took this as evidence that the European race was naturally stronger, and as such, it was perfectly natural for the indigenous population to die out as they were seen as the weaker race.

This extreme philosophy was taken even further in the 1840s by Dr Thomas Arnold, a professor of history at Oxford. He proposed that at any one time throughout history, there was a dominant race that achieved its potential and then passed on their achievements to a stronger, more capable race, Arnold (1842). A conclusion that was drawn from this theory at the time was that, if true, there was a possibility that one day the European civilisation may cease to exist and be taken over by a race of black people. This was of particular concern as during the colonial era Europe had control over large parts of the world, and in particular, Africa. This gave rise to the fear that European domination could be ended and the roles of coloniser and colonist reversed. In his book, 'The Races of Men', Dr Robert Knox, a Scottish anatomist and ethnologist, highlighted recent rebellions in parts of the British empire and other empires of the age, stoking the fear that Europeans might soon be expelled from their colonies around the world, Knox (1850).

These evolutionary arguments for racism clearly demonstrate how science was used to benefit the colonialist agenda. The theory of evolution, which is taken so much for granted now, was manipulated to allow the justification of acts of blatant racism and in some cases genocide. The removal of indigenous populations benefited the British empire and so the ideologies which justified it were allowed to flourish and become normalised.

3.3. Phrenology

Phrenology was a pseudoscientific practice developed by Franz Joseph Gall, a German physician in 1796, which involved the measurement of the skull to determine personal characteristics. Practitioners of phrenology believed the brain was divided into 37 separate organs, known as faculties, each of which represented a particular trait, such as 'calculation', 'secretiveness', 'friendship', and 'destructiveness'. It was thought that the more a person used a particular faculty, the bigger it would become, and that this would present as bumps on the skull. Phrenologists believed that by measuring the bumps on a person's skull, it was possible to predict that person's traits, Dempsey-Jones (2018).

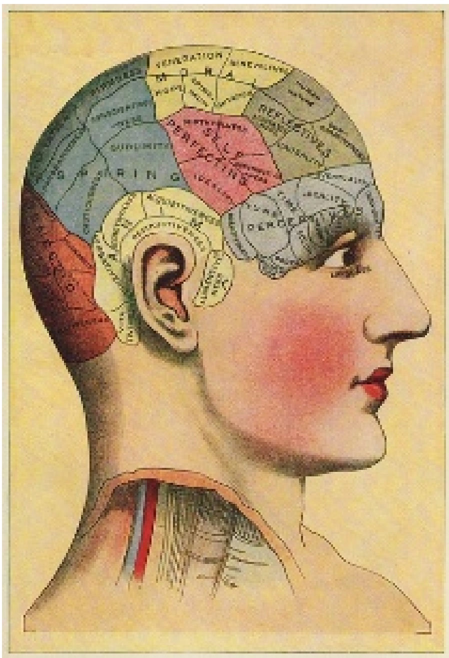

Figure 3. A phrenological diagram showing how the brain was split up into various faculties, the prominence of which could supposedly be determined by measuring an individual's skull. Image obtained from https://scopeblod.stanford.edu/.

Bank (1996) describes how phrenology was viewed as a respected field and enjoyed much popularity in the UK. Soon afterwards, it began to be used in racial classification and spread throughout the British empire, specifically in the Cape Colony, located in what is now South Africa, and Bank presents this quote from J. G. Spurzheim:

"The foreheads of negroes, for instance, are very narrow, and their talents of music and mathematics are in general very limited ... According to Blumenbach, the heads of the Calmucs are depressed from above, but very large laterally about the organ which gives the disposition to covet, and it is accordingly admitted that this nation is inclined to steal.", Combe (1830).

According to Bank, the earliest evidence of phrenology in the Cape can be found in the letters of Thomas Pringle in 1820, a poet and friend of some of the most influential phrenologists of the time. His letters detail his efforts to collect the skulls of people from local groups (tribes), and send them back to Europe to be examined. This was also a prevalent practice in Australia, where European phrenological institutes purchased the skulls of aboriginal people for examination, Kociumbas (2004).

This again shows the pattern of scientific specimens being collected in the colonies and exported to Europe to be studied and classified. There was no respect for any of the people whose remains were taken, and they were treated like objects to prove an ultimately racist scientific theory.

Bank discusses that phrenology held a special appeal to colonial overseers in the Cape. In particular, the settlers of the Cape Colony almost completely rejected phrenology to begin with, and expressed more liberal and egalitarian views on race, preferring to believe that any difference in race could be attributed purely to environmental factors, as opposed to any intrinsic biological difference. This did not fit with the agenda of the colonial elite however, who rejected the idea of racial equality and saw phrenology as an opportunity to justify not just racism, but any actions taken against the indigenous population. Using a 'scientific' argument legitimised their position. An opportunity to do this came with the Xhosa wars in the 1830s and 40s. It provided many skulls to examine and confirm phrenological arguments, and the hatred towards the Xhosa people made the European settlers more open to the idea of the intrinsic superiority of Europeans over the indigenous people. These two factors, in combination, brought phrenology to the forefront of scientific racism not just in the Cape Colony, but in the wider colonial world.

Phrenology was also used widely in the United States in the early 19th century to justify slavery. At this period in time, the abolitionist movement was gaining popularity and phrenology provided a strong argument against it. A physician during this period, Charles Caldwell, used phrenology to assert that all African people had larger faculties of 'veneration' and 'cautiousness', and so were suited to servitude under a master, Hann (n.d.). This allowed proponents of slavery to claim that it was in fact for the enslaved peoples' own benefit, as they were incapable of being trusted with freedom, Ruane (2019). Ruane also describes the diagnosis of a supposed illness, known as 'drapetomania', by the physician Samuel A. Cartwright, which allegedly gave slaves the desire to run away, and was attributed to their 'smaller brains and blood vessels'. To attribute the natural human instinct of freedom to a disease specific to one particular race highlights the confidence white people had in their superiority over other races and that it was seen as being only natural for African slaves to be in servitude.

4. Diffusion of science and the Eurocentric bias

Science is recognised in the literature as having a significant Eurocentric bias. From the beginning of the colonial period, scientific thought was dominated by a particular approach to the scientific process, the Baconian method, Adas (2016). This method was the foundation for the modern scientific method and emerged as a rival to Aristotelian thinking. It allowed the universe to be seen as providing raw material and legitimised the use of nature for the advancement of society, Alam (1977). Adas describes how science at this time was seen as being neutral, and based on empirical reasoning, which gave Europeans scientists the confidence that Western science was not constrained by human borders and was intrinsically valid. Thus it was seen that the spread of European science to the rest of the world was not only inevitable, but beneficial. However, due to the absolute certainty in the Western scientific method, indigenous epistemologies were disregarded and were rarely studied, except from an antiquarian viewpoint. In this way, science created a lack of respect for other, more natural scientific viewpoints, and founded a hierarchy which served to legitimise colonial control, Villafuerte (2020). This is summed up in a quote from "The West and others: History of a supremacy", a paper by Sophie Bessis:

"The paradox of Western science lies in its ability to produce universals, elevate them to the rank of the absolute, violate the principles that derive from them with a fascinating systematic spirit, and then elaborate the theoretical justifications of these violations.", Bessis (2002).

Thus it can be seen that science allowed the creation of a supposedly empirical and neutral viewpoint from which to study the world, and then, using these flawed empiricisms, justify anything that suited them.

4.1. Models of scientific diffusion

The way in which scientific thought has diffused throughout the world, and in particular the perception of the diffusion, has massively influenced the Eurocentric bias. As such the following section carries out an in depth review of two important papers in the field of scientific diffusion theory.

4.1.1. Basalla's theory of diffusion Basalla's 1967 paper "The spread of Western science" is heavily debated within the literature. However, it is recognised as an important work in the discussion of the diffusion of science. The aim of this paper is to explore how Western science spread to the rest of the world. His paper begins by claiming that modern science was developed entirely in a small number of western European countries and he then acknowledges that colonialism and military endeavours played a crucial role in spreading Western science to the rest of the world. However, Basalla wishes to explore this diffusion in more detail, to answer questions such as: 'Who were the carriers of Western science? What fields of science did they bring with them? What changes took place within Western science while it was being transplanted?'. In order to do this, Basalla proposes a model for scientific diffusion characterised by three stages. In stage one, Western science is transferred to the nation in question; in stage two, there is a period in which colonial science is carried out, and in stage three there is, as Basalla terms it, a 'struggle' for the nation to develop an independent scientific culture.

While Basalla's model is technically correct, it takes a very Eurocentric view to scientific diffusion. For example, in the opening lines of the paper, Basalla refuses to acknowledge that Western science could have had input from any other than a select group of Western European nations, and when he describes the first stage of his model, he uses the term 'nonscientific' to refer to the region to which European science is being transplanted. However, he does acknowledge that this does not refer to a lack of scientific development in ancient times. Thus it can be seen that even though there is an acknowledgement of pre Western science, it is dismissed without any discussion. This pattern of European superiority continues throughout the paper, where he briefly acknowledges that natural history was studied in Japan, but was taken over by European scholars because of their 'superior classificatory system'. When discussing that there were some colonial scientists who surpassed the greatest minds in the European scientific community, Basalla recognises the works of Benjamin Franklin, a scientist and one of the Founding Fathers of the United States, and even goes so far as to call him a 'hero'. However, there is no similar mention of scientists from non-European backgrounds in other parts of the world.

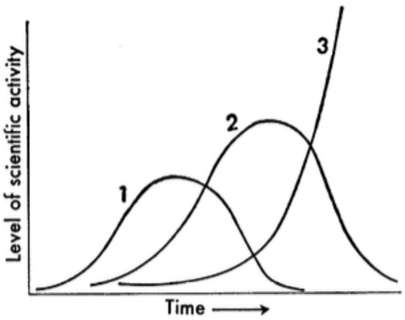

Figure 4. George Basalla's model of scientific diffusion. The three stages are clearly marked. However, it does not account for the influence of indigenous science on European science, Basalla (1967).

The criticism of Basalla's model extends to other areas of the literature. For example, Arnold (2000) notes that because Basalla viewed science as neutral and universal, he saw the spread of Western science to the rest of the world as inevitable and even beneficial, and also refused to consider that colonised peoples may not have been willing recipients of Western science. Arnold also critiques the lack of acknowledgement of non Western science in Basalla's paper. However, as Chakrabarty (2015) notes, Arnold himself still advocates a Eurocentric diffusion model, saying that colonial science in India can only be understood as conjunction with British control. Chakrabarty acknowledges the pre Western scientific thought in India and recognises that Indian scientists developed technology which had not been invented by Western science. From examination of the surrounding literature, it can be seen that scientific diffusion is not as clear cut as it may first seem. Although colonialist expansion did allow Western science to spread around the globe, many of the places it spread to had rich scientific traditions of their own, which in turn contributed to Western science.

4.1.2. Joseph's theory of diffusion In his paper "Foundations of Eurocentrism in mathematics", Joseph (1987) provides an in-depth history of the development and transmission of science. He acknowledges that there is a Western bias in science, and that this arises from the perception of the development of science through the ages. It is therefore important to study in detail where certain aspects of maths and science originated and how they have spread between cultures in order to combat the prevailing notion that science is a uniquely Western achievement.

The discovery of mathematics from the Egyptian and Mesopotamian cultures dating to around 2000BCE coincided roughly with the 'scramble for Africa'. This was a period in the late 19th and early 20th centuries when Europe began to partition Africa, and European control of the continent increased dramatically from 10% to almost 90

Joseph presents the typical Eurocentric model for scientific diffusion as it was seen at that time. It is characterised by two main periods of scientific development, one taking place in Greece, from approximately 600BCE to 300AD, and the other from the renaissance to the present day. In this model, these two periods are separated by an era known as the dark ages, so called because of the stagnation of scientific and technological advancement, especially when compared to the post renaissance period, at least in Europe. This model assumes two main things: 1. That there was no contribution to maths by pre Greek societies, and 2. Between the time of the ancient Greeks and the renaissance, there was not only no scientific development in Europe, but anywhere else in the world. These two points are fundamentally untrue; there is evidence to show rich mathematical knowledge in many pre Greek civilisations, such as in Egypt, Mesopotamia, and Babylon, and the dark ages were, at least outwith Europe, anything but. There is almost a millennium of scientific advancement made by many different cultures throughout this period. However, an interesting conclusion can be drawn from this model. This is that the refusal to acknowledge any non European science, both pre Greek and during the European dark ages, clearly shows a Eurocentric bias in the way people perceive the history of science. European scientists preferred to believe that they were the natural successors to the Greeks, and that any meaningful scientific development could not have happened outside Europe in the intermediate years.

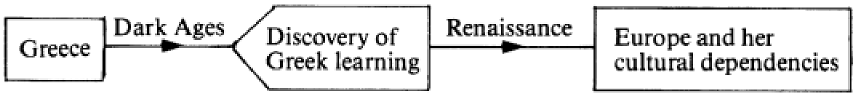

Figure 5. The traditional Eurocentric model of scientific diffusion. This does not account for any pre Greek science, and assumes that there was no scientific development anywhere in the world during the European dark ages, Joseph (1987).

Joseph then proceeds to provide a slightly updated model of diffusion. In this model, there is some recognition of the contributions of pre Greek civilisations to maths and science. However, the acknowledgement of this contribution is likely to be minor at best, and entirely dismissive at worst. This is despite major mathematical discoveries by these civilisations, in particular the understanding of Pythagoras' theorem and a method for solving quadratic equations which went unimproved until the time of Newton.

This is particularly evident in "A short account of the history of mathematics", a book written in 1888 by W. W. Rouse Ball, a fellow of mathematics at Trinity College, Cambridge. In this nearly 500 page book, only nine are devoted to the study of the pre Greek maths of the Egyptians and Phonecians. While there is an acknowledgement of maths before the Greeks, the overall tone of the chapter is dismissive, using phrases like: "a nation may possess considerable skill in the applied arts while they are ignorant of the sciences on which those arts are founded", and when discussing how much the ancient Greeks owe to civilisations before them: "it is probable that this sums up their indebtedness to other races", Ball (1888). From this it can be seen that while there is some limited recognition of science in pre Greek civilisations, there is a reluctance to devote any considerable time exploring how it helped shape modern science.

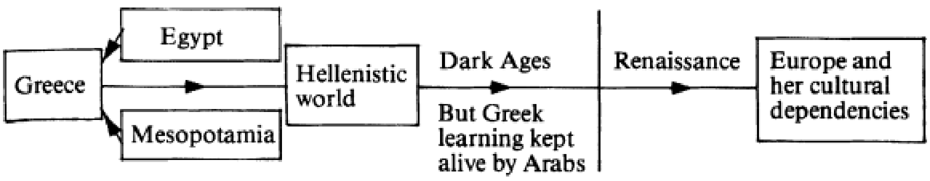

Figure 6. A slightly updated but still inaccurate model which acknowledges some pre Greek science, and differentiates the science of the Hellenistic period from that of Ancient Greece. This model also acknowledges that Arab scientists aided in the diffusion of science to Europe but only recognises them as preserving Greek knowledge, and not contributing to it in their own right, Joseph (1987).

This model also separates the classical Greek period (600-300BCE) from the post-Alexandrian Greek period (300BCE-300AD). This is an important distinction as in the classical Greek period, while there were distinct city states and thus cultures, the people were ethnically similar, and shared the Greek language. However, after Alexander the Great's military campaigns, the demographics in the region changed drastically, and many different groups of people in Asia became part of the empire. The construction of the city of Alexandria in Egypt provided a major centre for not only trade, but the exchange of ideas and learning. This allowed people from many different cultures to come together: not just Greek and Egyptian, but Phonecian, Persian, Jewish and even Indian. This is important as it demonstrates that even during a period where the advancements in maths and science are seen as Greek, there was actually a wide range of input from many different cultures, many outside of Europe.

The final feature of this model is that it gives a slight recognition to the work done by Arab scholars during the dark ages in Europe. There were many influential scholars during this period, and massive achievements in both maths and the physical sciences were made. However, the revised model only acknowledges that Arab scholars kept Greek teachings alive, and does not account for the massive contributions that Arab scientists made in their own right.

The third model that Joseph presents is mainly concerned with expanding the details around the period labelled the dark ages. As discussed above, the term is commonly applied to world history as a whole, regardless of the evidence showing a rich scientific history outwith Europe, particularly that of Arab scientists. The model shows that scientific knowledge which was developed in India, China and the Hellenistic world was then transferred by Arab scholars to major learning hubs, such as Jundishapur in Persia; Baghdad, the capital of the Eastern Arab empire, and also the capital of the Western Arab empire, first in Cairo, and then moving to Cordoba in Spain. The model highlights that Spain and Sicily served as important centres of learning not just in the Arab world, but for scholars from Western Europe as well, who travelled to these places in order to study both ancient and modern science.

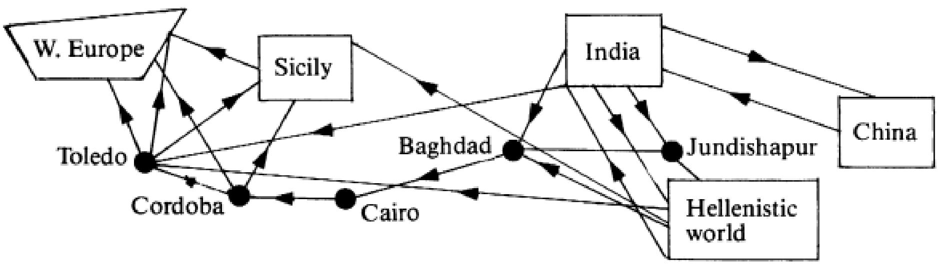

Figure 7. A more comprehensive model of scientific diffusion throughout history, which shows the pattern of scientific diffusion into Europe from various other cultures, and includes major centres of scientific learning from around the world, Joseph (1987).

Another important feature of the diagram is the one way arrows pointing to Western Europe. These demonstrate the transmission of science from India and China by Arab scientists, who in the intermediate years added massively to this science, to finally terminate in Western Europe in the 15th century. This demonstrates just how much of modern Western science is built upon and indebted to non European science and scientists. Despite the clear historical evidence for the diffusion of science from outside Europe to within Europe, there is very little recognition in the literature for non Western science, especially during the period labelled 'the dark ages'.

5. Non Western science

As has been seen above, the Eurocentrism pervasive in science has not just established Europe and the Western world as the main centres of modern science, but has also led to a disregard of any science produced outside of Europe. As discussed, this stems from the perceived superiority of the Western scientific method, developed during the renaissance and spread throughout the world during the conquests of the colonial era. However, there is a wealth of non Western science from around the world that is neglected, and often treated with contempt, Joseph (1987). Non Western science encompasses hundreds of individual cultures' achievements, and so it is impossible to do it justice here, however, it is helpful to look at a few examples.

There is a rich scientific history throughout Asia, with massive advances made by Indian, Arab, and Chinese scientists. Indeed, the 'four great inventions of ancient China', paper making, gunpowder, printing, and the compass, preceded the European development of these concepts by hundreds of years, Snively (2015).

There are many examples of pioneering scientific methods in Africa, however, most African science, beyond that of the Ancient Egyptians, is often overlooked, Blatch (2013). Blatch also describes some of the massive advances in science and technology: the Dogon people of Mali made such accurate astronomical measurements (that some modern historians suggest that undiscovered European influence, or even aliens, are to be credited for their knowledge); metallurgical insights allowed the production of tools, art, and possibly even a precursor to the steam engine; there were medical advances with not just a wide knowledge of how to use native plants to treat a wide range of conditions, but also evidence of vaccinations, autopsies, and even brain surgery.

Snively also talks about indigenous science in the Americas. The native population were adept at using plants and herbs to treat illness, and according to Ross (1966), over 70% of the world's pharmaceuticals have come from the active components of plants used by indigenous populations.

There are also some concrete benefits to learning about and appreciating the importance of non Western science. In particular, conservation efforts can be helped massively by indigenous knowledge. While Western science can often study large areas, the local indigenous knowledge can provide insight into the area's past, and help to document changes in the local environment going back hundreds of years, Ravilous (2019). So it can be seen that using Western science and indigenous science in conjunction can actually provide benefits that would not be seen otherwise. Also, in education, teaching about indigenous science in schools can help students feel more engaged, and reduce the foreignness of European science for non European students, Joseph (1987). Baquete (2016) concurs with this, explaining that where indigenous scientific knowledge comes from everyday life, teaching this in schools can help students feel more engaged than just learning about abstract scientific principles.

5.1. Indian maths: the modern numeral system and zero

The number zero is absolutely crucial to modern maths and science. Without its use, many of the things that are taken for granted would never have been developed, and so it is easy to assume that the concept of zero is something that has always been known about. In actual fact, the use of zero as a number is much more recent than one might think. Zero as a placeholder has existed for much longer than the number. The Babylonians used it as a way to signify the absence of any digits within numbers, separating tens from hundreds etc. The Mayans also devised zero to be used as a placeholder in numbers, but it was never developed into a number in its own right, and there is some evidence to suggest it was used as a placeholder in the Sumerian culture, between 3000-2000BCE, Yates (2017).

The first recorded use of zero as a number comes from the Indian mathematician Brahmagupta, who described the use of zero in calculations some time in the 7th century.

However, Brahmagupta himself did not claim to have invented zero, Szalay (2017). The ZerOrigIndia Foundation is an institution which focuses on research pertaining to the origin of zero, and in a paper by one of their coordinators it is described how even before it was used in a mathematical framework, zero existed in Indian culture, as the concept of nothingness, or emptiness, van der Hoek (n.d.). This was a principle in Indian philosophy and was given the name 'sunyata'. The word for zero in Hindi is 'sunya', and so there is a clear link in the etymology of these two concepts. Van der Hoek describes that there has been no conclusive research done to uncover which of these terms came first; did the mathematical concept come from the philosophical or vice versa, or are they even related at all?

However, if a clear link could be shown between the philosophical sunyata and the mathematical sunya, it would establish that one of the most important concepts in maths came from a spiritual background, thus providing a significant demonstration that the Western scientific method is not the only way in which maths can be done. It would lend credence to indigenous ways of knowledge which, because of the inherent Eurocentrism in science, were disregarded.

Zero made its way from India to the Arab world, and in 773, Al-Khwarizmi adopted it into the Arabic numeral system, where he used it in the development of algebra, Szalay (2017). It was the Arab occupation of Spain that brought zero to Europe. Here it was used by Fibonacci and introduced to the wider European population. Szalay describes how merchants used zero widely to trade with, but also how the Church saw zero as satanic. The Italian establishment banned the use of zero due to their distrust of Arabic numerals, and so this highlights again how the prevailing attitude of Eurocentrism and a disdain for non Western epistemologies led to the disregard of something upon which modern maths and science is founded.

Indian mathematicians were also crucial in the development of the modern numerical system. In the Vedas, a large volume of Indian religious text, dating to approximately 1200BCE, numbers are expressed as combinations of powers of 10. This allowed for the development of a decimal numerical system, and from the third century BCE, there is written evidence of the Brahmi numerals, a base 10 number system which is the basis for the modern numeral system. Towards the end of the 8th century, Arab mathematicians began to use Hindu numerals in maths and science, and it is through them that this system was introduced to Europe. It is the Hindu-Arabic numeral system which is used in the world today.

Comparison of selected modern systems of numerals

Hindu-Arabic	1	2	3	4	5	6	7	8	9	0
Arabic	١	٢	٣	٤	٥	٦	٧	٨	٩	٠
Devanagari (Hindi)	१	२	३	४	५	६	७	८	९	०

Figure 8. A comparison of Hindi, Arabic, and Hindu-Arabic numerals. It can clearly be seen that there is a definite similarity between them, despite the massive cultural and linguistic differences, Smith (n.d.)

There was also an acknowledgement of negative numbers in Indian mathematics. Brahmagupta, in addition to using zero in calculations, also demonstrated an understanding of negative numbers. He referred to positive numbers as 'fortunes', and negative numbers as 'debts', Yates (2017). Thus, from a practical approach he was able to come to an understanding of an important mathematical concept. This may seem insignificant at first, as negative numbers are taken as a given in modern maths and science. However, the concept of negative numbers was not immediately obvious in other mathematical cultures. For example, the ancient Greeks, for whom maths was based on geometry, considered negative numbers to be irrational and nonsensical, since negative lengths, areas and volumes do not make any physical sense. The Arab mathematicians developed negative numbers further, but in Europe they were met with reluctance. Many mathematicians, even up until the time of Newton and Leibniz, considered negative solutions nonsensical. For example, Michael Stifel, who did extensive work on exponents and logarithms, refused to acknowledge negative results, calling them 'numeri absurdi', and Chuquet, another renaissance mathematician, used negative numbers within calculations but also described negative results as absurd, Johnson (1999).

European maths and science suffered greatly because of this. Negatives were crucial to Leibniz when he developed calculus, and yet for hundreds of years they were treated with skepticism and doubt, Yates (2017). The fact that Brahmagupta developed the concept from a practical viewpoint, and not in the way which Western science dictated things should be done, by observation and empirical proof, demonstrates that it is fundamentally wrong to dismiss other epistemologies just because of an innate bias. Had the Western scientific community adopted negative numbers hundreds of years earlier, mathematics may be much more advanced than it is today.

5.2. Arab science

One of the most important regions in the development of science and maths was the Arab world. While today it is seen by many as 'backwards' and 'ultraconservative', for many years the language of science was Arabic, al-Khalili (2008). Professor Jim al-Khalili describes how it was an Abbasid caliph, al-Ma'mun, who kickstarted the golden age of Arabic science. He set up the Baghdad House of Wisdom, a major centre for learning and teaching in the Arab world, and it was during this period that major scientific developments took place under Arab scholars. For example, al-Biruni, an Iranian polymath who lived in the 10th and 11th centuries, has been described as an equal of Leonardo da Vinci, and it has been theorised that Copernicus's measurements were based on the work of the astronomer Ibn al-Shatir, Faruqi (2006). A basic theory of evolution was proposed by an Arab scientist, al-Jahith, almost a millennium before Darwin, and it was Ibn al-Nafees who developed the first correct model of blood circulation, even though credit is usually given to William Harvey, an English doctor who lived approximately 400 years later, al-Khalili (2008). While there are undoubtedly far too many figures of note to examine here, two scientists in particular stand out for their groundbreaking developments which have influenced science and maths well into the modern era.

Figure 9.

Figure 10.

Figure 9: Isaac Newton, 1642 - 1726. Often considered one of the most influential figures in science. Image obtained from https://wellington.rsnzbranch.org.nz/.

Figure 10: Ibn Al-Haytham, 965-1040. Published 96 works on optics, geometry, astronomy. He remains largely unknown despite much of Newton's work building on his. Image obtained from en.wikipedia.org.

One of these scholars was al-Khwarizmi. A Persian mathematician, Muhammad Ibn Musa al-Khwarizmi can be credited for many mathematical developments. He helped build on trigonometry, and worked on over 100 tables of trigonometric values; he used an approximation of pi to calculate the areas of various shapes; he developed the method of false positions, an algorithm for calculating roots, and in fact the word algorithm is a corruption of his name, Kettani (1976). But perhaps his most important achievement was the invention of algebra. In his book, "Kitab al-jabr wa al-muqabalah" he sets out the principles of balancing and reducing, and transferring terms from one side of the equation to the other. It is from this that the term algebra comes: al-jabr became algebra. Al-Khwarizmi used the principles set out in his book to solve linear and quadratic equations, a pioneering method at the time, Faruqi (2006). However, more importantly, algebra is one of the fundamental foundations upon which maths, science and technology is based, but even given its importance, al-Khwarizmi is seldom given credit for his work, and is largely unheard of.

Another, perhaps even more influential scientist was Ibn al-Haytham. Born in Iraq in the latter half of the 10th century, al-Haytham has over 96 published works on fields ranging from optics to pure maths to astronomy. He proposed a theory of vision and light, theorising that light reflected from objects and into the eye, and thus described the eye in terms of an optical instrument, Rashed (2002). He discovered how light was refracted and devised the physical law behind this, for which credit has been largely given to Snell, seen in the eponymous Snell's Law, and has been called the 'father of modern optics', Kettani (1976). He is also recognised as being the 'first true scientist', al-Khalilli (2009). This is due to his work on the experimental method. He promoted the use of experimentation in scientific study, and the laws derived by him were based on such experiments, Rashed (2002). His work has been described as influencing that of Roger Bacon, the founder of the Baconian method of science, upon which modern science is built. However, credit for experimental science is often attributed to the great scientists of the renaissance: Newton, Descartes, and Galileo, Faruqi (2006).

From the literature discussed above, it can be seen that even though most people may not be aware of it, there is a huge amount of non Western science which in many cases is wrongly attributed to European scholars. In addition, it demonstrates that European science is clearly built on the achievements of scientists from other cultures and that without these developments, science as a whole may not be where it is today.

6. Modern day effects

The close link between science and colonialism has had many lasting effects into the modern era. The domination of science by Europeans throughout the colonial period has led to a very Eurocentric way of thinking about historical scientific development and science in general, as was discussed earlier. In particular, the near extinction of non Western scientific methods, in conjunction with the pattern of colonial science being reduced to field work has resulted in difficulty for former colonies establishing their own scientific community, and has left them struggling to keep up in a world where society is based on Western science, Adas (2016). Even after countries were granted independence, they preferred to invest in Western science instead of reinvigorating their own scientific traditions, Alam (1977). This is because, when given the choice between which type of science to embrace, Western science is seen as a way to modernise and play a larger part in the world, and indigenous science is seen as outdated and irrelevant. By looking at the history of colonial science, it can be seen how this dependence is directly linked to colonialism, Harrison (2005), and even years after formal decolonisation, it is still prevalent.

This can be seen in the way in which scientific knowledge is valued. For example, most scientific journals and societies are based in the Western world, Villafuerte (2020), and the annual league tables for universities are published by Western universities, Roy (2014). So it can be seen that the Eurocentric viewpoint of science is still very much prevalent and has concrete impacts for developing scientific communities in other parts of the world.

This has also established itself in the way scientific research is conducted. A study found that of papers published in Central Africa, 80% of them are conducted in conjunction with a partner country outside the region, and in many cases, this collaborative partner was in fact the former coloniser of that country, Boshoff (2009). However, as Villafuerte (2020) notes, this relationship is more likely to take the form of a dependency rather than an equal partnership, and scientists in the non Western country are more likely to be involved only in fieldwork, that is collecting samples and data, than they are in the analysis of publication. De Vos (2020) describes this dependency in the framework of 'parachute science'. Parachute science, de Vos explains, is the phenomenon whereby researchers from external countries, usually based in Europe or North America, come to another country to carry out research, which usually involves the help of local scientists, before returning to their home country to publish. This has created an imbalance in scientific attribution, and means that there is a reliance on outside experts to actually get anything done, i.e. published, whereas the people that carry out the fieldwork are rarely acknowledged.

Roy (2014) discusses how health charities attempting to help in pandemics in previously colonised parts of the world have faced backlash and mistrust. After hundreds of years of brutal colonial rule, indigenous people are not always eager to trust in what they see as a continuation of the unequal scientific community. One particular example of this was in South Africa during the AIDS crisis. Previously in colonial South Africa, epidemics were used to justify relocating the native population away from their homes to make room for White settlers, and so when Western research linked HIV to AIDS, the findings were met with mistrust, Fassin (2003). Some people viewed this as a ploy to make Black South Africans look promiscuous or unhygienic, and the president of South Africa at the time, Thabo Mbeki, refused to acknowledge the link between HIV and AIDS, and so limited the use of antiretroviral drugs, which could potentially have saved the lives of between 300,000-400,000 people, Boseley (2008).

7. Were there any benefits of colonialism?

Some claim that there were definite benefits of colonialism. As has been seen above, colonialism allowed massive strides to be taken in many different fields of science, and this may be seen to have had a positive impact on colonised people. For example, the advancements in medicine, and in particular treating tropical diseases led to better hygiene standards and quality of life, Arnold (2006), and technological developments like the railway systems helped link colonies to world trade, increasing the income of a majority of African countries, Heldring and Robinson (2013). However, these must be critically analysed in the context of colonialism and the impact on indigenous peoples it entailed. To do this, there are two prominent scientific ethics debates which can shed light on this argument.

7.1. The case of Henrietta Lacks

We can examine two instances of breaches in scientific ethics. Firstly, the case of Henrietta Lacks. In 1951, Henrietta Lacks, an African American woman died from cervical cancer. In the months leading up to her death, doctors had taken swabs which they gave to a researcher without her knowledge or consent. This researcher discovered that her cells had some incredible properties that made them extremely useful in medical research. They were distributed widely to other labs and today they form a crucial component of biological research, and have been used in finding treatments for some cancers as well as in immunology. However, the family of Henrietta Lacks was never given any compensation from the massive profits made by bio-research companies, and her name, medical records, and genome were made public without consulting the family, Butanis (n.d.).

Figure 11. Henrietta Lacks, the woman behind the HeLa cell line, which has benefited countless people through its use in IVF, vaccines, and cancer treatments, Ahluwalia (2020)

The method by which these cells were obtained, and the resulting distribution and research was medically unethical, and so it is hardly surprising that some people believe that the use of the cells should be reduced or even eliminated entirely, and that by continuing to use them, it condones the injustice of their origin. However, Henrietta Lacks' family advocate for their continued use, as long as scientists acknowledge the person behind the cells, as a way to celebrate her life. They also believe that the continued use is warranted because the HeLa cells have helped to treat cancer and help couples conceive through IVF, Nature (2020).

7.2. Pernkopf's Atlas

Another instance of a violation of scientific ethics can be seen in Perkopf's Atlas. This medical work was collated by Eduard Pernkopf, an Austrian doctor who was an avid supporter of Nazi ideology and, after the Nazi rise to power, was made dean of the medical school at Vienna University. The Atlas contains very detailed anatomical sketches, which are of use to doctors and some of which even rival modern computer imaging technology. However, the ethical debate arises from the fact that some of the drawings may have been made from the dissections of executed Nazi political prisoners, Begley (2019).

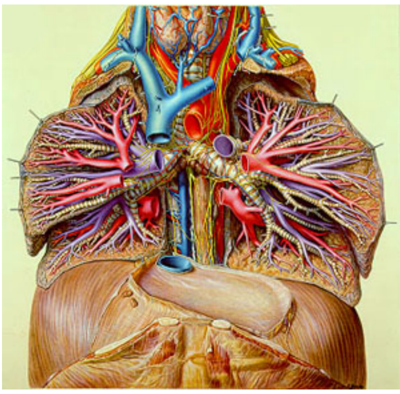

Figure 12. A diagram from Perkopf's Atlas. The detail and colouring in this book is second to none, making it a valuable, but controversial resource for surgeons, Batke (1937).

Obviously, some take the view that it is completely unethical to use the Atlas no matter the reason, saying that the method by which the drawings were obtained taint the work and that by using it, similar atrocities may be condoned in the future. However, others argue that it is in fact permissible to use the Atlas as it is a tribute to the people who died, and that it reminds us about the atrocities committed under the Nazi regime. Also, it may serve as a reminder of what can happen when science is viewed as supremely objective, and that the human cost of any scientific research should always be considered, Atlas (2001).

These two examples help give context to the place of colonialism in scientific development. As evidenced by the literature discussed earlier in this report, colonialism was key to the development of many scientific fields and technologies. Objectively then, colonialism was a force for good, allowing pure scientific advancement for hundreds of years. However, although science may be seen as objective, in the context of colonialism it was most certainly not. Science and colonialism were linked, and as such, the atrocities and barbarities carried out in the name of colonialism taint scientific progress as well. From the two examples above, there are two options: to shun modern science and the exploitative base on which it was developed completely, or to recognise the benefits of science for billions of people, while also acknowledging the deaths of millions due to colonialism.

8. Conclusion

In conclusion, the literature shows that science and the colonial expansion of European nations were closely linked and that colonialism was crucial to scientific progress for hundreds of years. However, science also benefited colonialism, making expansion faster, cheaper, and more efficient. It was also used to control indigenous populations and to wipe out indigenous epistemologies, allowing the creation of a compliant colonial elite.

The scientific justifications for colonialism were also examined, showing how the European domination of science allowed the discrimination and dehumanisation of other races, and justified acts of barbarity carried out in the name of colonialism. Science allowed the European powers to act as if colonialism was in the best interests of colonised peoples, even when perpetuating acts of genocide.

The literature around the diffusion of science was studied and it was shown that there is considerable Eurocentric bias when talking about the spread of science, with limited acknowledgement of any non Western science. However, other, more inclusive models of scientific diffusion were acknowledged, and it was shown that European science is very much built on the scientific advances of other cultures.

Also acknowledged were examples of non Western science, with particular focus on Indian and Arab scientists and mathematicians. From this it was seen that crucial developments in maths, science, and technology can be attributed to many different cultures, and that again, European science owes a huge debt to scientists from all over the world.

The modern day effects of colonialism on science were considered and it was shown that there still exists a culture of dependency and mistrust in scientific collaboration between Western and non Western countries. Some specific examples were examined to show the concrete effects of this mistrust, and the phenomenon of parachute science, which characterises the dependence, was presented.

Finally, the possible benefits of colonialism were considered, and some important ethical debates used as a framework in which to analyse the role of science in colonialism.

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