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Philosophy of Science: An Exploration through Geological Case Studies

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Abstract

Science, especially the field of geology, cannot be separated from culture. Through an examination of six different philosophies of science and relevant case studies, this work will highlight how foundational geologists created and developed their theories in order to align with cultural constructs, specifically religion. As technology progressed and competing viewpoints arose, the field of geology has become more and more complex since the 17th century. Therefore, this piece will conclude with an explanation of my own philosophy of science. This methodology aims to reconstruct our cultural cognitions regarding science, creating a method which acknowledges biases in the science based on our values, socioeconomic status, race, and gender.

Keywords

scientific method, geology, philosophy, religion

Comments

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Science, especially the field of geology, cannot be separated from culture. Through an examination of six different philosophies of science and relevant case studies, this work will highlight how foundational geologists created and developed their theories in order to align with cultural constructs, specifically religion. As technology progressed and competing viewpoints arose, the field of geology has become more and more complex since the 17th century. Therefore, this piece will conclude with an explanation of my own philosophy of science. This methodology aims to reconstruct our cultural cognitions regarding science, creating a method which acknowledges biases in the science based on our values, socioeconomic status, race, and gender.

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Dedicated to my dad, David Dinella.
Thank you for always encouraging
me to be curious.

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Essay 1: John Woodward & Deductivism

Introduction

Through an exploration of ancient Greek Philosopher, Aristotle, and 17th century geologist John Woodward, this essay will contend how religious beliefs, particularly the belief in a divine, perfect God, biases rational thought. These biases in turn pose challenges when relying solely on deduction to acquire scientific knowledge. This paper will outline key texts from both Aristotle and Woodward and compare and contrast their methodologies of reason. Further, this work will contest the validity of inferences regarding natural processes based on syllogisms, as well as the strengths and weaknesses of demonstrations.

Aristotle's Philosophy of Demonstration

Aristotle's philosophy stems from a lineage of academics beginning with Socrates, who believed that human intelligence was a gift from God. What set Socrates apart from his contemporaries was knowing our limitations even with our uniquely human consciousness. This notion is famously quoted as "I know that I know nothing" (Fine, 2021). It is arrogant of a man to assume he knows everything, but it is a sign of intelligence to comprehend that we only know a fraction of the natural world. Therefore, what mode of inference should we use to further advance our acquisition of scientific knowledge as there is so much to discover and comprehend?

Pioneered by Aristotle and accepted without challenge from philosophers for centuries to follow, syllogistic reasoning, also referred to as "demonstrations", are non-ampliative inferences based on metaphysical principles. Metaphysical principles, according to Aristotle, may be aggregated into four causes: the material, formal, efficient, and final cause (Gimbel, 2011, p.15).

If we want to deduce the “nature” of an object, we must understand its physical composition, where it came from, what processes brought about the object in its physical form, and its purpose (Gimbel, 2011, p.14-15). If we know all four of these causes, we in turn are knowledgeable of an object’s essence, and may be certain in the validity of our deductive inferences.

However, if we are to define natural processes through these four causes, it is also important to distinguish what exactly is considered “natural” according to Aristotle. In the opening chapters of *Physics,* Aristotle proposes a dichotomy between “shape” and “nature”; in other words, he outlines the distinction between the material and the principle (Gimbel, 2011, p.13). Aristotle further describes how he rationalizes natural essences through nodes of opposition. For example, nature is full of juxtaposing principles: i.e., if a number is not odd, it is even; if it is not a straight line, it is curved, if an object is not in motion is it at rest, etc. (Gimbel, 2011, p.14). Thus, Aristotle begins an inference on a broad subject, and then categorizes his reasoning based on a large topic at hand.

John Woodward’s Fossils

Throughout his work, *An Essay Towards a Natural History of Earth* (1661), Woodward refers to the “Great Deluge” as the efficient cause of fossilization in rock strata. As a colloquialism for Noah’s Flood as described in Genesis, the Great Deluge was held by Christians to be a natural disaster by the will of God, analogous to a clockwork mechanism as a consequence for humanity’s sins (Pleins, 2003). In general, scientific minds of the 17th century attempted to theorize how mechanical processes of the earth acquiesce with their religious beliefs, in attempts to remain reverent towards biblical scripture. Thomas Burnet, English author of the fundamental geologist text *The Sacred Theory of the Earth (*1681) believed that heat from the sun fractured the earth's crust displacing unprecedented values of water to cover all land masses (Pleins, 2003), by the hand of God but in a manner that he could rationalize using his scientific knowledge.

This intersection between religion and science is evident in Woodward's work first where he rationalizes the "parallel fissures" in rock strata, in addition to the fossils embedded between observed layers. For example, Woodward deduces that we observe similar mineral composition in rock strata in various continents because of how sediments deposited during the Great Deluge (Gimbel, 2011, p. 340). Withstanding that God is the divine creator, Woodward rationalized his findings through a theologian's lens. To Woodward, the earth was not billions of years old extending through large periods of geologic time, its age ranges in the mere thousands as the Bible proclaims. Therefore, the notion that plate tectonics have merged and separated, organisms crossing land bridges and the earth going through drastic climatic changes was unthinkable. Therefore, the deductive argument of Woodward may be summarized as follows:

God induced the Great Flood which changed physical processes of the earth.

Marine organisms only exist in the ocean.

Marine organisms are found in terrestrial sediment because of the Great Flood.

This argument is supported by claims by Woodward in his text:

Minor Premise: "…remains of the Universal Deluge, when the Water of the ocean, being boisterously tuned out upon the Earth, bore along with-it Fishes of all sorts…" (Gimbel, 2011, p.341). There was a flood induced by God, that displaced large volumes of water onto land.

Major Premise: “those which we find at land… that are not matchable upon our shores” (Gimbel, 2011, p.34). Marine organisms are only found in the ocean.

Conclusion: “That during the Time of the Deluge, whilst the water was out upon the terrestrial globe…” (Gimbel, 2011, p.341). It was the Great Flood that brought marine organisms to the terrestrial earth where we now see their remnants.

Further, Woodward’s logic to explain why marine fossils are embedded in mineral strata lays on the foundation of principles from his contemporaries of the catastrophism movement. Catastrophism contrasts ideologies developed by James Hutton’s uniformitarianism, which argued that geologic processes have always operated slowly and in the same mechanisms over time (Baker, 1998). Catastrophism was a middle-ground for geologists to study their discipline without compromising their religious beliefs, and attribute shifts in earth’s equilibrium to be one-time occurrences as a consequence by God.

To close his discourse, Woodward describes the exact mechanisms by which he believes why marine fossils would be enclosed in sediment, including Newtonian laws of Gravity as an integral component (Gimbel, 2011, p. 341). As established, the Great Flood brought marine life back to land, where the bodies of the organism broke down then coalesced (Gimbel, 2011, p.341). In order to do so, the divine forces of God bypassed all other normal natural processes, such as gravity, and forced together organisms in an otherwise unnatural manner. According to Woodward, this period of cohesion and burial of organisms only occurred once in the history of the earth and could not have any other reasonable explanation.

Aristotle and Woodward

Woodward asserts he is making “inferences” based on his journal observations, and never declares his suppositions as absolute truths. This diverges from Aristotle’s reverence towards deduction, in which we can believe with certainty a derivation of an unfalsifiable metaphysical property is also true.

Aristotle would disagree with Woodward primarily on the deductive logic that earth was created from a divine creator. Alternatively, Aristotle’s God is the “unmoved mover” who is in control of invisible forces but does not evaluate the morality of human behaviors (Sfekas, n.d.; Olson, 2012). Further, Aristotle’s philosophy suggests that the world has always existed in its exact form that he has witnessed; the universe and the terrestrial earth does not need an efficient cause because it has always existed just the way it is now (Sfekas, n.d.). In other words, Aristotle’s God is not Woodward’s Christian God, therefore the large metaphysical principle at which each of them derives their conclusions are vastly different.

Considerations and Discussion

It is indisputable that Aristotle has had a profound impact on how the modern scientific sphere conducts science, yet his reasoning is not without constraint. A significant fallacy in Aristotle’s deductive method is uncertain validity of the minor premise. If we base our inference on a broad universal truth that is not true, our deduction is also incorrect. This is due to the notion that deductive arguments contain a conclusion that does not have anything that is not contained in the premises. Woodward’s syllogistic reasoning, therefore, has fallen victim to this weakness if we view geology from a secular lens.

Woodward's science preceded that of Wegener and the theory of plate tectonics. For both Woodward and Aristotle, it was inconceivable that for billions of years our earth system has oscillated between glacial and warming periods, and how over large durations of geologic time our continents themselves have coalesced and separated. Therefore, it was not just one dramatic "Great Deluge" that has caused mollusks and calcium carbonate shelled organisms to become buried in rock--it has occurred many times over geologic time. Thus, to contradict Aristotle and Woodward, the earth has existed for an inconceivable large period of time, and humans have only existed for a small percentage of it.

With a secular perspective in conjunction with technological advancements in the field of geology, it is generally agreed within the scientific sphere that the age of the earth is approximately four and a half billion years old, and we have confirmed this through both observation with our senses as well as advanced technology such as radioactive isotope dating (Hall, 2007). In conjunction with Steno's Laws, radioisotope dating can confirm that the rock layers at greater depths are generally older in the span of geologic time scale and would suggest that the fossils became suspended prior to the proposed year of Noah's Flood (Hall, 2007). Conversely, Woodward contested that Noah's flood only occurred a few thousands of years prior to his writings, as opposed to multiple natural fluctuations diluted over time.

Another of Woodward's key misjudgments is his Newtonian connection. I would infer that if the *Peligae* shells were to settle downwards, they would be at the upper layers of the earth strata since they are relatively less dense than other marine organisms. This notion is supported by scholars of the Linda Hall Library, and highlights again, the key issue with the deductive method (Linda Hall Library, 2018).

Similar to other scientific disciplines, in geology, it is almost impossible to rationalize scientific evidence in the context of religion. For biologists, to not believe in evolution significantly pigeon-holes your perspective on biological concepts. However, if a scientist were to aim to integrate religion into their inferences, they should not solely rely on deduction.

Aristotle's weaknesses are easily discernible from a modern viewpoint, but he was undoubtedly a trailblazer for the entire field of science. Aristotle and his teachers are still integral to scientific discourse because a large proportion of the time, their teachings and the principles of deduction do hold true. Take the ubiquitous example when first outlining the framework of a deductive argument:

"All Greeks are mortal

Socrates is Greek.

Therefore, Socrates is mortal." (Gimbel, 2011, p.1).

Thousands of years removed this deductive argument is still regarded as true. Similarly, to how Socrates knew his limitations as a mortal, it is also imperative to be cognizant of the limitations of reasoning via syllogisms.

Further, Woodward lived in a time of great scientific moral crises. During the seventeenth century, a rapid influx of great minds and opposing thoughts facilitated a dichotomy between academics who chose to remove religion from the equation all together, and those who attempted to rationalize it (Pleins, 2003). It is not a sign of intelligence to support one faction or another, however, from my own beliefs on religion and my position as a scientist, I am more likely to support a scientific claim that is secular in nature. Frankly, I believe there is too great of an abundance of empirical scientific inferences to support supposed truths about our earth (i.e., its age, physical composition, biological history, extinction events, etc.), that Woodward may not have been confronted with.

Conclusion

Aristotle's principles of deduction led academics for centuries through the web of unknown principles of our natural world. Methods of demonstration provided structure to outline what we observe through the senses and what metaphysical principles we yielded as true. Yet, the validity of deductive inferences is ultimately dependent on context, which often are complicated by cultural, religious, and technological factors.

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Essay 2: Plutonism, Neptunism, & Induction

Introduction

The inductive approach of conducting science emerged at a time where human perception of the world was rapidly changing. This essay will explore the eliminative method of induction proposed by John Stuart Mill and its connection to geologist, James Hutton, and his theory of the earth. Although the ampliative nature of inductive inferences provide us with probabilistic rational for natural processes, much like the deductive method, it is not infallible. While Hutton's logic gave us new insight of the earth's antiquity, and contrasted the prior held beliefs on how the world came to be, this paper concludes by asserting how there is never such a thing as true induction, as the human consciousness if far too interconnected with internal biases such as religion. Therefore, the claim of universality when asserting inductive inferences are far too abstract and intangible to confirm through repeated observations alone, particularly when attempting to decode a system as complex as our geologic world.

The Rise of Induction

Deductive logic, which often was reliant on metaphysical syllogisms, is a top-down approach to the logic of discovery. Methods of demonstration were pioneered by Aristotle in the third century B.C.E. and dominated the scientific sphere until the 17^{th} century (Macleod, 2016). Thus, as humans learned more about the world around them, the one-size-fits-all method of doing science according to deductive logic was destined to be challenged.

The rise of induction was concurrent with the age of Enlightenment in Western Europe (1685-1815), also known as the "Age of Reason" (Manuel, 1951). A core principle of the Enlightenment was the unified drive of intellectuals to refine society through rational thought, inherently challenging prior beliefs about the world—such as questioning the prominent role of a divine creator (Manuel, 1951, p.25). Thus, early inductivists found great fallacy in the deductive method, questioning the validity of logic where the premises are impossible to confirm using direct observation of the senses (Gimbel, 2011, p. 43). Further, the Enlightenment was a time where those beyond the religious sphere could contribute to the acquisition of scientific knowledge. Once one realizes anyone can observe and perform science, the divine rights bestowed by God for governmental leadership and moral order risks being overthrown.

Contrasting to non-ampliative deductive arguments, inductive inferences have conclusions which go beyond the scope of the supporting premises (Gimbel, 2011, p.43). According to Baconian philosophy, inductive logic draws generalization *a posteriori:* where one derives unfalsifiable truths from experimentation or observation (Manuel, 1951, p.29). Isaac Newton adds in *Rules of Reasoning in Philosophy* that we may assign the same causes to the same effects and have the causes be “esteemed universal” until proven otherwise (Gimbel, 2011).

John Stuart Mill (1806-1873) expanded upon these general methods of inductive inference placed by his predecessors. Mill rejected *a priori* logic via deduction and argued that the human mind is an integral part of nature; therefore, we can only make conclusions based on our mind and senses (Macleod, 2016). Thus, causes and their effects, according to Mill, should be experimental in nature. Therefore, in the *System of Logic* (1843), Mill described five canons to create his framework for refined, eliminative methods of induction.

The first of Mill’s canons is the *method of agreement, w*hich asserts that if two or more phenomena has only one circumstance in common, the shared circumstance is the ***probable*** cause. In other words, A (the cause) is a likely requirement for B (the product), so if A doesn't occur, then B also does not occur (Gimbel, 2011, p.59).

The second canon is the *method of difference*: when A does not occur, B still occurs. If the effect happened without the predicted cause, then we know for certain that A is not the antecedent of B (Gimbel, 2011, p.60).

The third canon, *the joint method of agreement and difference*, combines the principles of the preceding two, reasoning that if we employ different methods and still observe the same conclusion, it is even more probable that the proposed cause is true (Gimbel, 2011, p.62).

If we can pair multiple causes with their relative effects with a degree of certainty, then whatever remains is probably the cause for the unpaired effect (Gimbel, 2011, p.64). This fourth canon is regarded as the *method of residuals.*

Finally, to address effects that vary in magnitude, Mill proposes *the method of concomitant variation* (Gimbel, 2011, p.67). If we change the degree of intensity of a cause, then we see proportionate changes in the effects, which can either be positive or negative.

Neptunism

Geology is a unique field of science as there is rarely the opportunity for empirical experimentation. There are inevitable complexities with theorizing how the world came to be, especially since most landforms and rock strata preceded human existence. Thus, it is challenging to confirm or deny the rate and the means of natural processes, and reasoning relies on observations within capacity at a given moment. Nevertheless, there were two predominant theories in geology during the 18^{th} century to attempt to make sense of our terrestrial world: Neptunism and Plutonism.

Abraham Werner, a key figure in the field of minerology, was also the pioneer of Neptunism, the etymology in reference to the Roman god of the ocean, Neptune (Leddra, 2010, p.29; Leddra 2010, p.83). Although Werner did not have a firm stance on the intersection between science and religion, his views were heavily supported in the United Kingdom for how nicely his theories paired with the epistemology of Noah's Great flood (Leddra, 2010, p.83). According to Werner's theory, there was a past time on earth where all land was covered by water. During this time, a variety of rocks were comingled into somewhat of a "rock soup" by which they crystallized out of overtime as the ocean receded (Leddra, 2010, p.84).

By these means, denser rocks like granite and basalt precipitated first, as evident by their placement at the peaks of the highest mountains (Leddra, 2010, p.84). At the lowest plains and valleys, we can observe sandy and silty soils which precipitated last (Leddra, 2010, p.84). In between these two extremes altitudes, we can observe sedimentary rock formations such as limestone and sandstone (Leddra, 2010, p.84). Separate from the theory of evolution and descent with modification, Werner further explained that complex life forms did not exist in the ocean at the time when denser rocks precipitated from the rock slurry, therefore these formations do not have embedded fossils. Conversely, fossils in sedimentary rocks hold "more complex life forms" that could survive and thrive as the "ocean became cleaner" as more and more rocks precipitated out (Leddra, 2010, p.85).

Plutonism, James Hutton and the System of the Earth

Often regarded as the "founder of modern geology" with an initial background in medicine and later a prominent agriculturist, James Hutton had a curious mind and a powerful impact on the scientific sphere. Hutton's most notable work is undoubtedly his 1788 publication in the Edinburgh Magazine *System of the Earth* (Dean, 1992, p.6). Yet, his interest in geology came decades prior, after a powerful storm off the coast of Edinburgh in 1744 triggered a great landslide. (Leddra, 2010, p. 87). This erosive event demonstrated the capacity of natural processes to alter landforms over a short period of time, as well as exposing the rock strata for Hutton to study. There, he noticed angular unconformities that Hutton was driven to make sense of.

Therefore, like an inductivist would do, Hutton travelled throughout the European continent to make ***repeated observations*** to find additional instances of unconformity of the rock strata. Hutton's motivation was to gather inductivist evidence of how natural processes may change the terrestrial world. Via this exploration, Hutton was successful, and found multiple instances of angular unconformity in regions such as the Isle of Arran, Jedburgh, and Siccar point from 1785 to 1788 (Leddra, 2010, p.88).

Hutton's first point in his synthesis of observations, "System of the Earth", asserts that the world has not always been as we know it today and is not the product of divine creation. This notion is supported by his rhetoric regarding how the composition the earth "has been formed by the operation of second causes" (Gimbel, 2011, p.376) therefore, natural processes beyond the scope of God (the primary cause) are responsible for terrestrial landforms. Hutton supports this assertion through the observations of sedimentary rock that cyclically erodes and consolidates into new, sedimentary rock formations (Gimbel, 2011, p.376).

Further, Hutton's background in chemistry also facilitated his supposition that dissolved siliceous and sulphureous sediment can separate from a solvent, such as water, and fuse together (Gimbel, 2011, p.376). Additionally, rock strata differ between locations because each unique geography has experienced its own set of environmental conditions and forces, which influence natural processes such as crystallization and lithification (Gimbel, 2011, p.376). In other words, water alone cannot consolidate materials, but minerals are capable of precipitating out of a solvent and bind together over time. Moreover, Hutton reinforces the notion that the forces of water are not solely responsible for consolidation of sediments, and rocks have continuously formed and broken apart since the flagship flooding event (Leddra, 2010, p.86).

The second key inductive inference in Hutton's work is the role of subterranean heat as a as a cause for rock formation (Gimbel, 2011, p.377). By forces of heat and pressure, Hutton concludes "our land had been raised above the surface of the sea" (Gimbel, 2011, p.375).This is central to the theory of Plutonism, contrasting Werner's theory that dense rock such as granite and rock precipitated from the water. A supporting argument for Hutton's inference is the notion that igneous intrusions from earth's heating and cooling violate Steno's law of superposition, where new rock permeates the strata of older, sedimentary rocks. This young rock that disrupts horizontal layers of rocks are therefore products of volcanic activity (Gimbel, 2011, p.376).

Hutton and Mill's Methods

Hutton's inductive inference may be summarized as follows:

I see evidence of new rock formation and the erosion of old rock.

I have seen this cyclical formation and erosion of rock in many different places.

The earth is not in a steady state; rock is continuously formed and eroded.

The more evidence that was observed by Hutton and other geologists, the more the theory of Werner's Neptunism was challenged. Mill's law of residues is the most applicable in this instance: if we exclude premises that we know are incorrect, the residual theories have a significantly greater probability of being correct. For example, large crystals and angular uniformities could not be from a great flood by Noah, as geologists Venetz and Agassiz supported Hutton's theory by describing past glaciation events as one of the many erosive causes (Bushman, 1973, p.42). Accumulating evidence continuously challenged the predominant theory of the young age of the earth, a mere few thousands of years old, and supported Hutton's inductive inference of earth's antiquity.

Yet, Plutonism does not encapsulate the whole story of the earth. A key component of Hutton's work was how volcanic eruptions triggered by subterranean heat can cool to form igneous materials. Although this event by itself is sudden and drastic, the natural law of the cause is constant (Bushman, 1973, p.41). This concept of a repeatable, predictable natural processes is in part how Plutonism evolved into Lyell's uniformitarianism: cause and effect patterns that we see happening today have been the same processes that occurred on our earth millions of years ago (Bushman, 1973, p.41)

Further, Hutton's assertion of Earth's ancientness was somewhat controversial. For many followers of the Christian bible, the earth was estimated to be only 6,000 years old (Repcheck, 2008, p. 36). However, Hutton himself did not reject religion, and still believed in the role of God. As Bushman (1973) quotes: "We shall thus also be led to acknowledge an order, not unworthy of Divine wisdom, in a subject which, in another view, has appeared as the work of chance, or as absolute disorder and confusion" (Bushman, 1973, p.44). God, according to Hutton, created the universe as we know it but has been *laissez-faire* since (Wromblewski, n.d.).

This role of religion uncovers an important factor when examining inductive inferences. Belief in God is metaphysical principle which will inherently confound all conclusions from subconscious biases: no single human is a blank slate. There is the risk then, that the observations we seek out are derived from subconscious deductive principles, as seen for those who believed God's will then form a consensus around catastrophic events by God as the cause . Further, the falsifiability of catastrophism highlights that although you may observe confirming evidence for an infinite number of observations, it takes few observations to disprove a theory.

What doesn't fit?

In terms of Hutton's fallacies in his inductive argument, there are two main shortcomings. One of which is that we cannot assert that nature is uniform. As aforementioned, Hutton's theory of the earth includes both slow and rapid processes, but how can one universal law encapsulate both contrarian ideas? Even if we establish that rates can vary, is there benefit in the knowledge of an interval of ranges, and how can we accurately quantify time and space before humans existed? With modern metrics of measurement such as the soil erodibility index (USDA, n.d.) , we may be able to calculate the erosive forces of an area over time, but we cannot say all erosion occurs at the same rate. Erosive forces are both geographically and temporally dependent, therefore we cannot implement Mill's fifth canon that the same degree of a cause has a proportionate influence on its effect. Further, because of the shortcomings of the human timescale, we cannot always observe the antecedent of an effect in a lifetime, therefore the method of agreement and differences are not directly applicable as there is no certainty whether A (the cause) did or did not occur.

We may be able to say erosion in one area is uniform, but it would be outrageous to assume that all nature everywhere is congruent-- hence a shortcoming with the inductive method in its entirety and universality. There will always be confounding variables that may invalidate our conclusion, and it is nearly impossible to account to the degree each additional factor may influence an inference. For example, erosion can occur from many different natural processes like rain, wind, the ocean, and the movement of glaciers (Bushman, 1983, p.42), and the mechanisms of each force vary. Further, if this erosive evident happened far in the past, the cause itself is not observable, only the effect. This highlights the challenge of geology where we cannot reduce complex, interconnected earth systems in an empirical laboratory setting; the scales of space and time are too great to model empirically.

Conclusion

Although induction provided a convincing new approach towards the logic of discovery, as we uncover additional information, "universal claims" via induction are inevitably overturned. Hutton's theories, despite serving as the foundation of modern geology, were ultimately imperfect. Plutonism was appended and changed following his lifetime, and geologists today are still uncovering new information about the earth. Additionally, induction in general cannot completely be separated from deductive logic, especially as many individuals believe in a divine creator--which will never be able to be proved or disproven. Therefore, although induction was introduced as a purely empirical method, its shortcomings are a result of the human condition.

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Essay 3: Catastrophism, Uniformitarianism, & Hypothetico-Deductivism

Introduction

William Whewell and his hypothetico-deductivist model emerged at a time where intellectuals in Europe were reforming the methods of science. However, the belief in the existence of God and the faith in the divine creation of the world from this primary cause or otherwise led to a severe division within the scientific sphere. This division was particularly sensitive for geologists, manifesting the catastrophism vs. uniformitarianism debate. This essay will provide an exploration of the procedural method of science according to Whewell, and how it is applicable to Charles Lyell's notion of uniformitarianism. Particularly, it will argue that neither the uniformitarian nor the catastrophist perspective can be regarded as a one-size-fits-all model of the natural world. Further, it will explain how scientific challenges arise when geologists attempt to explain how the world came to be during a period where humans were not able to directly observe processes so dispersed across space and time.

Whewell's Hypothetico-Deductivism

William Whewell was a prominent figure in numerous fields of scholarship. His work has launched the trajectory of history, economics, philosophy, and science, all while concurrently serving as an Anglican clergyman (Oslington, 2017, p. 593). Inevitably, the majority of his work integrated theological ideologies. This intersection was not an attempt to prove the existence of a God but to develop a greater understanding of God's creation or infer the organization of systems to appease the almighty power (Oslington, 2017, p.578). Despite this, Whewell existed during a time of great theological division in Europe, where belief in God was continuously challenged by the rationalists (Garrat, 2010). Empiricists of the time were focused on rigorously modeling and testing the natural world to explain fundamental truths about our universe, therefore rejecting the notion of divine creation from a singular God (Garrat, 2010, p.23) .

Nevertheless, one of the pivotal landmarks of Whewell's academic career was outlining the system of hypothetico-deductivism in his work *Novum Organum Renovatum*. With his title directly referencing Francis Bacon , Whewell's method integrates both induction and deduction. However, it's important to note the Whewellian version of induction is not synonymous with Bacon's method of induction, as induction according to Bacon simply is an ampliative inference based on repeated occurrences (Gimbel, 2011, p.43). Whewellian induction uses the colligation, or the joining of known facts to create a new product to add to the scientific sphere in the form of a hypothesis (Laudan, 1994, p.370).

Further, Whewell disregards the logic of discovery in favor of the "context of justification", hence the claim of the new instrument, *renovate*, or renewed (Gimbel, 2011, p.91). According to Whewell, we can begin the process of science by any means we choose. Scientists don't need rational justification and should have the freedom to seek answers to creative questions. These questions lay the foundation for the hypothesis, its Greek roots directly translating to "under" and "theory". Thus, Whewell's construction of a hypothesis reiterates the notion that a hypothesis is based on some degree of aggregated preexisting knowledge, regarded as the "colligation of facts", where the scientist attempts to make sense of how to tie these known facts together, much like a pearls on a string of a necklace (Gimbel, 2011, p. 96).

Then, a scientist should form a prediction: if the hypothesis is true in each circumstance, then it is expected that one will make an observation that supports the hypothesis. Further, the testing of the prediction dictates how the scientist should proceed: if the predicted observation occurs, then the hypothesis has inductive support. These tests, according to Whewell, are most often constructed experimentally in a controlled system, so that we know from our direct observation a given truth. Repeated instances of the hypothesized observations serve as evidence that the hypothesis is probably true. Contrastingly, if the predicted observation does not occur, the hypothesis is rejected via *modus tollens*. *Modus tollens* uses deductive logic to assert that if the antecedent is false, the conclusion is also false (Gimbel, 2011, p.93). Therefore, the scientist should restructure a new hypothesis if the predicted observation did not occur, since based on syllogistic reasoning we have no means to believe that the hypothesis would be true.

The final stage of Whewell's method is the consilience of inductions. According to Laudan (1971) in "William Whewell on the Consilience of Inductions", this consilience can occur in three circumstances:

1) When a hypothesis is capable of explaining two (or more) known classes of facts (or laws).
2) When a hypothesis can successfully predict 'cases of a kind different from those which were contemplated in the formation of our hypothesis'.
3) When a hypothesis can successfully predict or explain the occurrence of phenomena which, on the basis of our background knowledge, we would not have expected to occur.

In other words, once we have inductive support for a hypothesis, how can we apply it to other circumstances in our natural world or larger theories? If we have probable cause via the hypothetico-deductive method to believe that the hypothesis may be true, the scientist has contributed to progress within the scientific sphere. Additionally, even if we do not have inductive support to a hypothesis, it is considered as scientific progress for now we know what suppositions regarding the natural world are false.

Catastrophism vs Uniformitarianism

The Catastrophism vs. Uniformitarian debate was among the progressives of the Geological Society of London during the mid-19th century, and somewhat of a competition among peers (Cannon, 1960, p. 40). In fact, most members in the geological society agreed with James Hutton's theory of geology and the notion that the state of the earth is not in a steady state, as outlined in the groundbreaking 1788 publication *Theory of the Earth* (Cannon, 1960, p.40). The division, however, was upon the rates of these changes and theological beliefs.

The catastrophes were led by Adam Sedgwick and William Whewell, the latter being the pioneer of hypothetico-deductivism himself (Cannon, 1960, p.38). To the catastrophes, the intensity of geological forces was greater in the past than in the present. Further, the changes in earth were short-lived and from a primary cause, therefore occurred on a worldwide scale (Cannon, 1960, p.38).

In its entirety, the catastrophism movement was an attempt to interlock scientific theory and theology. One of the prime examples of this intersection is the notion of the Great Flood as the cause for the state of the earth as we know it. According to the story of the great flood, land was covered by earth for 378 days where high intensity rainfall caused the sea-level to rise incrementally (Leddra, 2010, p.96). Belief in this story in conjunction with dominant theories in geology led to unique conclusions. For example, based on the law of superposition and the notion that rock strata are superimposed, older rocks will be towards the bottom of a given area, while younger rocks will be closer to the surface. Catastrophes argued that since we see great densities of simplistic marine fossils in the older layers of rock, these species became embedded in the rock during the early stages of the flood (Leddra, 2010, p.96). As sea level continued to rise, more complex organisms such as amphibians fell victim to the forces of the flood as well, which is why we see greater densities of complex organisms in layers of rock towards the top of a rock sequence (Leddra, 2010, p.96). In sum, catastrophism was a directional theory, while uniformitarianism was cyclical.

As intellectuals learned more about the world beyond the European continent through landmark explorations, geologists such as Charles Lyell could not agree that the act of God was the only driver of geological formations. The patterns in the rock strata that may have been congruent in Europe but were not the case in other parts of the world. Therefore, according to Lyell's uniformitarianism, the geosphere is in constant destruction and renewal, and the patterns that are shaping our world now have also happened in the past.

Charles Lyell's Principles of Geology

One of the main arguments in chapter five of the first volume of Lyell's *Principles of Geology,* was the notion that natural forces we can observe in the present can guide us on the mechanisms of earth's past. We may only make these claims if we reject the "delusion" that the earth is a mere few thousands of years old. Thus, Lyell argues we must renounce the age of the world according to Genesis (Lyell, 1830, p.76). In fact, Lyell patronizingly writes that the belief that natural processes are reliant solely on a primary cause is analogous to believing in supernatural beings like demons, ghosts, and witches (Lyell, 1830, p.76). Contrastingly, Lyell's foundational text argues that instances of fluctuation and change of the earth (i.e., floods, earthquakes, comets, eclipses) are due to “fixed and invariable laws” (Lyell, 1830, p.76). This text may be organized into the hypothetico-deductive model as follows:

1. Lyell begins by questioning how the world we know it has come to be: How are geological formations, specifically sedimentary rocks, formed? What is the time scale of these natural changes such as erosion and deposition?
2. He then constructs his hypotheses based on the preceding question:
    a. H_0 :The rate of natural processes has been consistent for the entirety of the geologic time scale from secondary causes, and these processes are cyclical (Lyell, 1830, p.80).
3. Lyell accounts for observations and decides if they match the predicted observation:
    a. “Man observes the annual decomposition of crystalline and igneous rocks and may sometimes see their conversion into stratified deposits…” (Lyell, 1830, p.83). Therefore, within a man’s lifetime, we see erosive processes happen each year from weathering. Secondary causes may include various forms of weather such as wind and rainfall. This provides evidentiary support that change is gradual and constant.
    b. During the lifetime of man, we have evidence that a single “earthquake may raise the coast of Chili for a hundred miles to the average height of about five feet.” (Lyell, 1830, p.80). Due to this observation, we may infer that after thousands of years, this increase in height will equate to the height of a mountain chain. (Lyell, 1830, p.80).
    c. Through advancements in technology, geologists now have tools to explore rocks of subterranean origins (Lyell, 1830, p.85). For example, Geologist Vitaliano

Dorati found similarities between the composition of rocks from the Adriatic Sea and the Apennine Hills of Italy (Lyell, 1830, p.84). Further, through a mixture of relative dating techniques and direct observations of marine species, Dornati concluded that fossils embedded corresponded to the existing general living in the Adriatic Sea. This directly contrasts the prevailing notion that the rock strata at the high peaks were "created in the beginning of things by the fiat of the Almighty (Lyell, 1830, p.85).

4. Consilience of inductions is met as follows: since many natural processes are observable in a single lifetime, it would be "inconsistent with all calculations and chances to suppose them to happen at one and the same time" (Lyell, 1830, p.80). Therefore, the hypothesis in its entirety refutes the Catastrophism perspective.

In sum, to Lyell, the earth experiences slow processes over a long-time scale. Interestingly, this fundamental principle of Lyell's uniformitarianism may also be applied to the biological scientists, and was a great inspiration to Charles Darwin (Cannon, 1960, p.39). In the context of species extinction, populations may decrease over a long period of time due to environmental stressors such as resource availability, competition, or changing climate, but their niche is eventually filled by another (Cannon, 1960, p.39). This is a further example of the cyclical nature of earth's processes, with the constant replacement of species over epochs. Thus, the directionality of catastrophism was contrasted by a secular view of the possibility that the earth was not perfectly created and stagnant; but is alternatively experiencing complex changes diffused over space and time.

What Doesn't Fit?

Hypothetico-deductivsm, in general, has its shortcomings. Of the principal critiques of hypothetico-deductivism is the possibility of irrelevant conjunctions. In this case, although a hypothesis may align facts in a logical matter, it still has the probability of being incorrect (Crupi & Tentori, 2010). This is most evident in the case of the catastrophes, who incorrectly connected sedimentary fossils to the Great Flood. They were able to justify their logic using factual evidence, but if the premises of the argument, belief in a God, confounds all logic, then the ultimate conclusion will also be incorrect. However, the notion of the catastrophes was not challenged until it became more strenuous to colligate existing facts when previous colligations were contradicted.

Similarly, the uniformitarian worldview selects factual evidence to support slow processes and deselects any factual evidence that suppose otherwise. Inherently, the uniformitarianism worldview does not account for natural variation--erosive forces within the same geography in a given year is not uniform. For example, an intense storm may erode a hillside causing mass movement, compared to the marginally impactful rill erosion from rainfall. In fact, from a modern perspective, more intense and frequent weather events as a result of climate change drastically alters the "status quo" weather conditions in a given era. This contradicts the uniformitarianism argument that conditions are constant from epoch to epoch, as our natural world varies intensely on both a short and long-time scale (Cannon, 1960).

In sum, the dichotomous nature of the uniformitarianism vs. catastrophism debate negates any possibility that the fraction of the other theory is correct, therefore excluding factual evidence that may be true but not relevant.

Another possible issue with Whewell's model is outlined in Hempel's response to induction via the Raven's Paradox (Gimbel, 2011, p.134). This infamous paradox asserts that the contrapositive of a condition is equal to the condition (Gimbel, 2011, p.134). In other words, if observation O is evidence for hypothesis A, and hypothesis B is logically equivalent, then the observation is also evidence for hypothesis B. The prime example of logical equivalent hypotheses for Hempel is:

Hypothesis A: All ravens are black.

Hypothesis B: All non-black things are non-ravens.

Therefore, according to the paradox, a white t-shirt, a blue scarf, and a red chair would all be considered evidentiary support that all ravens are black.

Geologists cannot form models and experiments for the geologic time scale, therefore the conditions for inductive support according to the hypothetico-deductivist model are impossible to hold constant. The only inductive support possible in the field of geology is through observations. Lyell was cognizant of this limitation, asserting that we cannot claim a certain process has occurred if the "operation is invisible to us" (Lyell, 1830, p.81). Therefore, the raven's paradox is directly applicable in the context of a primary cause. We cannot see God, and we cannot see him directly alter the state of the earth, therefore it provides evidence that it is a process that occurs naturally and slowly. For example:

Hypothesis A: The cyclical change in the earth is from constant secondary causes.

Hypothesis B: The cyclical change in the earth is not from a primary cause.

Both hypothesis A and B are logically congruent, but just because we don't witness acts from a primary cause does not indicate that everything occurs uniformly. The prevailing critique of uniformitarianism is that it proposes "there is only one way in which ancient causes are equal to present ones" (Song & An, 1996, p.83). Song and An (1996) also assert that Lyell's uniformitarianism was instrumental in rejecting the intervention of God but is now anachronous in the field of modern geology, therefore it should be viewed from a historical perspective a no longer a valid theory (Song & An, 1996, p.85). Despite the multiple volumes and years of revisions, Lyell's uniformitarianism is inherently flawed as it does not account for any other possibility. In other words, it is misleading to claim that either uniformitarianism or catastrophism is the one true law for a system as old and complex as the earth.

Conclusion

The hypothetico-deductivist model was an important instance of progress in the field of science, but its application varies between disciplines. Thus, like pure deductivism and induction, it has various shortcomings in asserting natural processes of the world on a grand scale are true. However, one of its key strengths was its permission of scientists to ask questions based on their own design and provided a route of how to interpret evidence to support their claim. Yet, despite through verifying a hypothesis through inductive, probabilistic reasoning, in context of the uniformitarianism and catastrophism debate, what does one do if both competing hypotheses have a likelihood of being true? Neither worldview, one confounded by creationism nor the other too bold to account for anomalies, is completely true. Both select relevant evidence, and both according to Whewell's method, have instance that support their validity. Therefore, it's important to note that forming a specific hypothesis is of the utmost important. If the hypothesis is too broad, it will inevitably have conflicting evidence, especially in the geological field.

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Essay 4: Plate Tectonics & the Holistic View of Theories

Introduction

Throughout the history of science, ideas inevitably change, but this dominant discourse is ultimately decided by those within the scientific sphere with executive power. Thomas Kuhn in *Structure* outlined how the field of science is both experimental but also inseparably human, as social hierarchies hold the authority to designate what the scientific community regards as valid factual evidence and progress. This paper will examine the notion of Kuhn's paradigm and how the "correct" process of science is dependent on the context of time and place. Further, it will investigate the connection of paradigm shifts to Alfred Wegener's theory of continental drift, and how this anomaly was the catalyst for a new paradigm regarding how the field of geology explains the processes which have shaped the natural world. This paper will at heart emphasize sociopolitical factors such as religion, funding, and technology and how such influences may alter the state of scientific paradigms.

Thomas Kuhn's Holistic View of Theories

Thomas Kuhn was an American-born 20th-century philosopher who redefined how we frame science. Most famous for coining the terms "paradigm" and "paradigm shift" via his 1962 publication *Structure,* Kuhn created a new comprehensive framework that integrated both the sociology and the logic of science (Marcum, 2008, p. 33). According to Kuhn, a paradigm is a holistic view of science that encompasses the scientific community's entire body of beliefs or foundations (Marcum, 2008, p.48). Further, a paradigm is based on social hierarchies and relationships between people. Therefore, scientists often perform "normal science" within the paradigm, which uses pre-approved methods, instruments, and logic to match the paradigm to new parts of nature (Marcum, 2008, p.48).

The process of normal science according to a paradigm may be summarized into four steps. First, one should define central terms. If conducting a study regarding the motion of an object, for example, this central term would most likely entail the laws of Newtonian mechanics. Therefore, for this context, it is assumed without a doubt that gravity on earth is 9.8 m/s^2. The second and third step of a paradigm focuses on defining questions that are meaningful and have legitimate ways of being answered. Following the example of Newton's laws, one may ask if we can study experimentally the speed at which two moving objects fall from a specific height. A possible question would be:

Does a tennis ball fall to the ground faster than a basketball?

One can test this question using metric instruments and "legitimate methods," such as determining height from a metric measuring stick and using a stopwatch to measure time. This method will determine if one ball reaches the ground faster or not.

The last step then includes defining what would be considered a reasonable conclusion. When one finds that both balls fall at the same time despite having different masses, can we conclude that Newton's law of gravity applies to objects equally with no regard to weight? The conclusion is up to interpretation, as this study does not account for confounding variables, but it fits into the predetermined paradigm that is accepted by the scientific sphere.

Thomas Kuhn in *Structure* asserted that this procedure of normal science is analogous to solving a jigsaw puzzle, with this puzzle often having a predetermined solution (Gimbel, 2011, p.187). In other words, Kuhn writes how normal science is the actualization of a promise set by the paradigm through a logically designed method (Gimbel, 2011, p.185). Therefore, normal science does not uncover novel mysteries of natural processes, but we fall under the false proposition that science is progressing because the "puzzle-solvers," the scientists, choose problems that they expect to have guaranteed solutions according to the paradigm (Gimbel, 2011, p.187).

The design of the paradigm works well until the accumulation of anomalies (Gimbel, 2011, p.188). The first anomaly may lead to a crisis, but we do not experience a "paradigm shift" until those with power within the hierarchy of the scientific community collectively agree that there is a need to alter the dominant paradigm (Gimbel, 2011, p.193). One of the pivotal examples of a paradigm shift for the history of science was the Copernican Revolution of the 16^{th} century. Until Nicholas Copernicus, the dominant view of astronomy according to the Christian church was Aristotelian (Kuhn, 1957, p.110). Aristotle's view of the universe was that the position of the earth is fixed, and other celestial bodies of the universe, including the heavens, rotate around the earth in concentric circles (Princeton University Press, n.d.). What Copernicus realizes centuries later through his education on traditional sciences, is that the purely qualitative observations on physics were not substantial (Kuhn, 1957, p.115).

Deriving mathematical models to support the notion of a heliocentric universe, with the sun at the center as opposed to the earth, Copernicus's work was a turning point for astronomy. This model also presented itself at a time where the political power of the churches in Europe was challenged, representing this "paradigm shift" and transitionary period when intellectuals could agree that the universe is structured by secondary causes, and not by a divine creator (Kuhn, 1957, p.4). Copernicus was in turn, one of the early anomalies of the paradigm that challenged previous biblical and classical authorities which allowed for a segue for a new paradigm of the universe supported by Newtonian mechanics (Greene, 2015, p.241).

Wegener's Theory of Plate Tectonics

This trend of institutional power has been prevalent in the scientific sphere for centuries following Copernicus. The belief in primary causes as for how the universe operates has never left the scientific discourse, particularly for the field of geology where we may rarely see a distinct cause and effect for natural processes that span the length of geologic time. One key example of this theologian struggle is evident through the exploration of how our continents came to be as we know it. The discourse around Alfred Wegener's theory of plate tectonics was undoubtedly the catalyst for a paradigm shift in how geologists viewed the earth system.

Until Wegener, the prevailing hypothesis in the field of geology regarding the continents was the presumption that land masses are remnants of past terrain and are in turn the remnants of larger land masses (Greene, 2015, p.240). Thus, the older land masses sunk, and the remaining land is fixed to their relative positions around the globe (Greene, 2015, p.240). The notion of the breakage of continents could be supported by both geologists who supported Lyell's uniformitarianism, under the supposition that erosive forces waste away the continents over time, or by the catastrophists who inferred the continents broke away due to the magnitude of Noah's great deluge.

This view was unchallenged until Alfred Wegener (1880-1930) began to wonder if there was an alternate explanation for the state of the continents as we know it (Greene, 2015). Born in Berlin, Wegener had a fruitful intellectual career and has expertise in a variety of scientific disciplines including astronomy, meteorology, geology, climatology, and psychology (Greene, 2015). In fact, his psychological study regarding “Gestalt reversals”, where rapid eye movement based on environmental stimuli may change an individual’s perception of reality was somewhat of a catalyst for his view of geology--if the brain can interpret data differently based on the interpretation of the environment, how we view the geologic world can change in the presence of new data (Greene, 2015, p.240). Wegener realized that the edges of the continents align in a way that they may fit together just like jigsaw pieces of a puzzle (Greene, 2015, p.240). Under the presumption of the alignment of continental coastlines, Wegener inferred that at one time, 200-300 million years ago, all the continents were compressed into one large supercontinent which he called “Pangea”, meaning “all lands (Well, 1997). Over geologic time from an unspecified force, these continents broke off from Pangea and drifted apart.

Wegener’s theory was a culmination of information after reading primarily reading three sources of text. The first of which was Austrian geologist Eduard Suess’s book *The Face of the Earth.* Here, Suess proposed that the field of geology should not be dichotomized into either minuscule (uniformitarian) causes and argued that large-scale changes can occur secularly, and the Alpine Mountain systems, for example, can be explained by secondary causes (Greene, 2015, p.243). Specifically, Suess hypothesized that mountain ranges formed from sequential overthrust faults, where continental crust is pushed upward by compressional forces. These overthrusts are not all gradual and minimal but require high volumes of force to yield such extensive results, not minimal forces that accumulate over millions of years. Similarly, the movement of the continental crusts may also be responsible for oceanic trenches, with one subducting under the other depending on age and density (Saigeetha and Banya, 2005).

The remaining two texts supported the existence of Pangea through biological means. Otto Krummel in *The Handbook of Oceanography* outlined how different shells for marine mammals are found in regions with similar chemical compositions (Greene, 2015, p.245). In other words, if the region of the ocean has high volumes of limestone in its bedrock, we will see organisms that have calcium carbonate shells. This notion pairs with the work of Theodor Arldt who in *The Evolutionary Development of the Continents and their Life-Forms* calculates the statistical summaries regarding the summaries of specific index fossils (Greene, 2015, p.245). In sum, the combination of these works led to the conclusion that due to the continuities in fossil remains and rock structures between continents such as South Africa and India, there must have been a time where these continents were connected due to their similarities in biological remnants, adding to the qualitative evidence of a super-continent (Saigeetha and Banyal, 2005).

A final key layer to Wegener's continental drift hypothesis was the existence of past glacial deposits and similar glacial scars in South America, Africa, and Antarctica (Earle, 2019). This existence of a Permo-Carboniferous glacier led to the conclusion that the supercontinent Pangea must have been located near the southern pole of the earth (Earle, 2019). Therefore, the continents could not have been fixed as we know it. The most comprehensible example of this in continuity is South America, located close to the equator of the earth. Due to existing knowledge on climatic patterns and the environmental conditions of the tropics, if the continents were fixed, there never would have been evidence for glacial erosion there.

Critical Interpretations of Plate Tectonics

Wegener's theory of plate tectonics was indeed a synthesis of existing knowledge that he decided to piece together in his own way. However, although Wegener's anomaly in the paradigm was revolutionary, it was not until fifty years after his proposition that it began to be accepted by the scientific community (Saigeetha & Banyal, 2005). The initial denial from

Wegener's publication was in part due to the lack of specificity in the mechanism for how plates can drift apart. This is somewhat analogous to previous paradigm shifts in science, where anomalies may appear but its acceptance as a new paradigm is gradual. For example, Copernicus' initial heliocentric theory manifested support from Galileo a century later, but the catholic church did not halt the ban on heliocentric books until 1783. Further, the Vatican did not publicly support heliocentrism. until 1992 (Cowell, 1992).

Throughout the 20th century, there was, however, an accumulation of additional evidence to support Wegener's theory. A large question in the field of geology before Wegener was how and why discontinuities in the path of magma exist based on their approximate ages. When a volcano erupts and the magma cools, it can tell geologists the direction of the Earth's magnetic field, as magma has a high volume of a magnetic mineral known as magnetite (Richardson, n.d.; Webb, n.d.). The dominant hypothesis regarding the changing direction of magma patterns prior to Wegener's paradigm was that the location of the poles has changed over time (PSU.edu). However, during the mid-20th century, geologists Keith Runcorn and Edward Irving sampled paleomagnetic wandering paths of magma on the European continent and used the angle of the magnetic fields to calculate the latitude at which it cooled (Webb, n.d.). In sum, this work supported the theory of continental drift as these calculations demonstrated that the continent of Europe has gradually moved north and was once, over 500 million years ago, south of the equator (Webb, n.d.).

However, these supports to the paradigm still do not account for Wegener's ultimate challenge of the *specific mechanism* for how continents moved. The prevalent hypothesized cause in the scientific sphere today is the earth's crust, also known as the lithosphere, which is separated into tectonic plates. These plates move gradually via convection currents from the heating and cooling of the molten iron and nickel from the earth's outer core (Saigeetha & Banyal, 2005, p.50). Under the assumption of plate tectonics, where there are seven major lithospheric plates, geologists can explain almost all natural formations--mountains are formed from the convergence of continental plates, deep sea trenches are formed from the convergence two plates where the denser plate subducts, and earthquakes are the result of tensional forces as one plate "slides" past the other; just to name a few of many examples of modern geological explanations of natural phenomena under this paradigm (Saigeetha & Banyal, 2005, p.50).

Referring back to Kuhn's description of a paradigm, it is important to note that according to Kuhn, paradigms are incommensurable. In other words, paradigms cannot be compared. Yet, until the social and political hierarchies support the new paradigm, they will not be accepted. That does not mean that one paradigm was more logical than the other, it may have just spun existing information in a new way or was missing key support from limits in technology. Therefore, the outlined advancements in the field of geology by collaboration and technological advancements in the 20th century were pivotal for creating a new paradigm centered around Wegener's theory of continental drift. Now, this is the pioneering theory that is taught in schools whether at the elementary or collegiate level (Saigeetha & Banyal, 2005, p.58).

Conclusion

Alfred Wegener's theory of continental drift is an excellent case study to model Thomas Kuhn's concept of the paradigm. Wegener's initial anomaly contradicting the preceding paradigm of how our continents came to be was gradually accepted by the scientific community as more information became available and it was interpreted in a new way. As we continue to interpret and perceive information in novel ways with the help of collaboration and technological advancements, it is quite possible that the geological paradigm set by Wegener may be overturned in the future. Yet it is important to conclude that these inevitable changes in how we attempt to nonexplanations for our natural world do not mean that past paradigms are illogical but instead emphasize the power of social groups in designating the direction of the central discourse.

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Essay 5: GIS & the Semantic View of Theories

Introduction

The semantic view of science emerged during the 20th century, concurrent with the cultural movement of pragmatism in America. In order to uncover the best avenues to answer scientific questions with available resources, the semantic view is centralized upon the formation of models. These models may manifest in different forms, but ultimately are designed to be used as tools used to investigate the natural world. This paper will investigate the semantic view of science and how successful modeling techniques can be for solving problems within the realm of environmental sciences. For geology specifically, the scale of the earth and rates of change from erosive processes is impossible to represent in its entirety. Therefore, it must be reduced into a more digestible, interpretable form via this application of models so we may better understand small-scale changes to supplement management decisions. Although using models are practical tools to answer scientific questions and have allowed scientists to make great strides to progress knowledge about our world, they should not be the only factor when investigating earth's natural processes.

Semantic View of Theories

Unlike the syntactic and holistic view of theories which suggest that theories are a set of propositions, the semantic view of theories rejects the notion of propositions in favor of sets of models. The semantic view contrasted with the "standard" process of science of the 20th century outlined by Thomas Kuhn, who proposed that scientists in the scientific sphere only found instances of truth according to a predefined paradigm (Gimbel, 2011, p.182). The semantic view of theories was a comparatively unsupported view within the context of the philosophy of science but revolutionary as it no longer relied on predefined knowledge.

Further, the semantic view asserts there is no such thing as a false model (Gimbel, 2011, p.231). Alternatively, some models are better than others, and some may be poor representations, but any model may be classified as useful if its instrumentalization is based on relevant information and logical judgment. Thomas-Jones (2012) expands upon the notion of a "good" model and how it may be valuable to the scientific sphere if it fulfills its intended purpose based on one's own interpretation. In this sense, if we consider a roadmap as a model to describe the path from one location to another, a "good" model would lead you to point A to point B. There may be alternative routes and paths one may follow, but if it is substantiated by reasoning, it is a valid and just model since it fulfilled its purpose.

Therefore, a well-crafted model may be used to create a clear explanation to explain phenomena, but it is especially valuable regarding parts of the world we cannot directly observe (Gimbel, 2011, p.231-232). Marshall Spector's essay "Models and Theories" (1965) challenged the view of his predecessors to emphasize the value of models as an instrumental tool (Gimbel, 2011, p.251). If we acknowledge that models will never perfectly represent universal processes, we will be able to appreciate their true value as tools. Spector argued that the notion of models was freeing, as theories derived from models are examined outside the calculus of corresponding rules (Gimbel, 2011, p.251). Breaking away from the shackles of observational predicates, he argued, can pave the way for innovation if we are not confined by our preconceived notions of right and wrong.

To further emphasize the applications of models, it is important to provide a broad overview of models in science and their multiple forms. The etymology of "model" may be traced back to the Latin word "modulus", meaning "measure" or standard (Frigg, 2023, p.3). In this context, model is synonymous with "notion" or "conception" and can manifest in various forms, both material and hypothetical (Thomas-Jones, 2012, p.3). Further, Max Black in "Models and Archetypes" (1960) asserts there are four types of models: scale, analog, mathematical, and theoretical.

Scale models "bring the remote and unknown to our own level of middle-sized existence (Gimbel, 2011, p.257). For systems beyond the scope of comprehension, we may condense the size with alternate materials on a smaller level so that we can access or manipulate the system (Gimbel, 2011, p.257). This scale model does not have to be a perfect replica either, it may be a selection of properties (Gimbel, 2011, p.257).

Analog models, like analogies, take a system we understand and apply what we already know to a system we want to better understand (Gimbel, 2011, p.233). Spector emphasizes that if "observable properties of the domain of the theory...are like the properties of the model…we can argue by analogy to the nature of the theoretical properties" (Gimbel, 2011, p.244). Black builds upon this point asserting strong analogue models are isomorphic, as sharing the "same structure or pattern of relationships" (Gimbel, 2011, p.258). An important distinction between scale and analogue models, however, is scale models are derived to imitate the original while analogue models correspond to an original system (Gimbel, 2011, p.258).

Mathematical models are representations of selected components of a system and are therefore inherently simpler than the real system (Gimbel, 2011, p.259). Mathematical equations are thus the linguistic compartmentalization of a process that, through calculations, is repeatable and provides an explanation of a phenomena. Further, these mathematical equations are empirical. Newtonian mechanics of motion would be a prime example of mathematical models as it has empirical support. Newtonian mechanics such as the formula for velocity (velocity= displacement/change in time) will give you an accurate estimate of the average speed of a moving object (Garanin, 2015, p.1).

Theoretical models are distinguished by a lack of empirical evidence and in turn is a representation based on assumptions about the system (Achinstein, 1965, p.3). Therefore, they are used as approximations and thus versions of theories themselves (Achinstein, 1965, p.5). Further, Achinstein (1965) argues that theoretical models most often serve didactic purposes (Achinstein, 1965, p.5). Although we do not have absolute certainty that it's correct and may never have the resources to confirm theoretical models due to limitations of scale, for example, we can learn many things from theories of systems.

A key principle in the semantic view is that one does not make inductive claims, but pragmatic ones. A central belief of the American pragmatism movement of the 20th century was the concept of testing the truth of a claim for its usefulness (Hookway, 2021). Pragmatists such as William James contest that if a model is incorrect or what we suppose is false, it just emphasizes there is still work to be conducted to minimize errors (Hookway, 2021). Therefore, the pragmatists do not drive for absolute certainty, but instead how we can make practical progress to improve our understanding of nature, which is also applicable and useful to help guide human intellect.

Geographic Information System Case Study

One of the biggest challenges in geology and the environmental sciences is quantifying the scale of environmental degradation. Scientists in the field are aware of erosive processes and how climate change may expedite rates of change, but GIS models are a useful tool to visualize the extent of the damages. Specifically, erosion along the coastlines is increasing due to the increased frequency and intensity of storm events, along with sea level rise as a result of climate change (Veira et al., 2021, p.2). Further, GIS monitoring can help environmental management by pinpointing which areas of a system are most vulnerable to maximize efficiency in implementing environmental solutions when limited resources such as time and funding, are scarce.

To study the Cananéia-Iguape estuary system, Veira et al. (2021) modeled both global methodology and vulnerability identification to make predictions regarding the environmental risk of the system over time. Cananéia-Iguape is located off the coast of Brazil, with mangrove forests serving as a vital buffer against storm erosion. In addition to providing an erosive buffer, these mangrove forests are essential habitat for marine and estuarine species (Veira et al., 2021). To assess vulnerability of this valuable region, Veria et al. (2021) included a mix of physical, environmental factors such as estimate of social erosion, deposition, and transport using field standard mathematical models, as well as anthropogenic data regarding socio-economic, demographic, and economic data of the region. Traditional vulnerability models only select for topographic features such as geology, geomorphology, and topographic elevation (Veira et al., 2021). What distinguished Veira et al.'s model from prior research was the integration of multiple perspectives, therefore their ultimate goal was to develop a model which to better understand both natural and human-induced factors on this jeopardized estuarine system to guide management decisions.

To collect data relevant to the model, Veira et al.(2021) used a hybrid of *in situ* field techniques and remote sensing data using GIS software. To further integrate human responsibilities, physical factors of erosion were distinguished between anthropogenic activities (AA) such as deforestation and natural dynamics (rock type, distance from coastline, maximum tidal range, etc.) (Veira et al.2021). First, the authors created various maps to assess each parameter individually, then created a singular map which concatenated features and weighted their impact to assess overall vulnerability. Their final product was a group climate vulnerability index (CVI) map and found that twelve percent of land (approximately twelve-hundred square kilometers) in the Cananéia-Iguape are at high risk of land degradation.

Semantic View and GIS?

GIS is a blend of different modeling techniques to holistically represent a system with all the information available. At its core, maps are scale models of the world. Reality is modeled through a selection of data and characteristics are represented within a two-dimensional space. In the case study of the Cananéia-Iguape system, although their selection of features integrates prior knowledge of known factors that impact erosion, they ultimately selected for features of their maps by their own will and logic. For example, the creators of the model did not include town names, business locations, or residential areas as these features are not applicable for the environmental focus of the model, nor did their absence hinder the comprehensibility of the map.

Furthermore, the specific means by which Veira et al. (2021) assessed vulnerability was via a mathematical model where a variety of parameters (x) that were multiplied by an assigned weight (n): $CVI=\sum Xi \times Ni$, where CVI is equal to the Climate Vulnerability Index. The paper chose to use this model as opposed to another approach to assess CVI, as opposing models were too sensitive to small changes in the individual classification actors (Veira et al., 2021).

This is consistent with the notion that although there may be various models that evaluate the same criterion, but the best model is always context dependent. Based on the collaboration of authors of the paper, they concurred the selected model was the most instrumental tool for their analysis, and selected relevant parameters based on their own judgment. Thus, the selected features they chose were not bound by a paradigm, but logically selected based on relevant information.

Further, visualizations were possible using ArcGIS software to highlight risk. In GIS, geographical areas are compartmentalized into pixels, known as raster data. The aforementioned vulnerability equation was calculated for each pixel and shaded with its respective color to convey what regions of Canéia-Iguape are most vulnerable to erosive forces exacerbated by natural and human-induced consequences of climate change. Their discussion of the model suggests it was successful as they desired to include a wide spectrum of parameters in hopes that it can guide conservation efforts towards the mangrove system. Thus, this research is a cog of a larger machine to prevent the total destruction of mangrove ecosystems worldwide which have experienced a loss of 35% in the past 20 years (Carugati et al., 2018). Additionally, this model adds significant value to the scientific sphere as the methods and analysis may be repeated depending on the region of interest.

Critique of the Semantic View of Theories

The maps from Veira et al. (2021) support the notion of the semantic view of theories as they perform well for the desired task (assessing vulnerability of land to sea-level rise and erosive forces) with the resources available via in situ field work and remote sensing. With innovations in technologies in the future, it is predicted these models will improve over time based on the limitations of the previous. This further emphasizes the key principle of the semantic view as there is no singular "perfect" model or way that you use models to solve a scientific problem. Yet, applications of GIS are valuable resources within the scientific discourse to emphasize how natural processes such as erosion are exacerbated by anthropogenic factors. Therefore, visualizing the threats in a way that a general audience can comprehend helps promote environmental issues in a digestible form so that stakeholders can make relative management decisions.

A significant drawback of GIS models is the possibility that study on a similar topic may select alternate features that would produce an alternate outcome. This variation in selection of properties may confuse the conversation. Therefore, if there is too much information produced than the public can understand, they may not have faith in the model since it is not reproducible. Critics of GIS software have also pointed out limitations if datasets are outdated or biased (Saastamoinen, 2022). Thus, the model is only as accurate as the training data. In order to mitigate these limitations, it falls upon the audience to be knowledgeable of such limitations and be skeptical when interpreting the message.

Models are undoubtedly useful to help compartmentalize complex systems into a way we can better understand and interpret. However, I would argue that it should not be the sole mode to better understand the natural world due to its subjectivity. A method of creating a model that is logical to one individual may not be logical to another, and therefore it may not be distributed and standardized. Therefore, geological models should be devised to answer a research question but should be compared to models within the same field. Thus, if multiple models made independently from one another represent the same meaning, there is probabilistic reasoning that the model is correct and useful by the validation process of induction.

Conclusion

The semantic view of theories has a number of strengths that add significant value to the progress of science. The ability to compartmentalize complex issues into models helps scientists answer large scientific questions by breaking down intricate systems into a more tangible form that they can manipulate and better understand. In the field of geology, mathematical and scale models using GIS are useful tools to represent how erosion may act upon a specific area over a specific time scale. However, due to limitations of models in both their derivation and distribution, models should be respected within the scientific sphere, but not the exclusive method of science.

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Essay 6: Discrepancies over the Grand Canyon & the Critical View of Theories

Introduction

The pursuit of knowledge will undoubtedly always be interconnected with human social structures. When the questioning of a natural processes occurred within a time frame that no current human was able to witness, such as in the field of geology, there are inevitably a multiplicity of interpretations one may favor as a result of preexisting biases. Through an examination of the dispute regarding Tom Vail's work *The Grand Canyon: A New View,* a creationist lens on the formation of the Grand Canyon, this paper will contest that there is no such thing as a clear distinction between science and politics—particularly religious institutions. However, it will acknowledge some key differences between the empirical nature of the scientific sphere opposed to the mysticism of religion, and how they cannot be directly compared. This piece will argue that as long as one acknowledges bias, that any knowledge should have the freedom to be distributed. Thus, it will concur with Feyerabend's conception of "epistemological anarchism" that the confines of the scientific method are ultimately impossible to abide by due to the inherent bias of the human condition.

Critical View of Science

One of the most significant critics in the scientific sphere is undoubtedly Paul Feyerabend, garnering attention from one of the most elite journals, *Science,* which even named him "worst enemy of science" (Kidd, 2011). What made Feyerabend so controversial was his assertion that an empirical scientific method did not exist, and instead claimed that science is confounded by those in power within society (Couvalis, 1997). Further, a key claim in his work

Against Method (1974) is that science cannot be isolated from historical context and thus is biased (Gimbel, 2011, p.281). In fact, his work emphasizes his frustration with how “the role of social and political rhetoric [is] substituted for rational methodology” (Gimbel, 2011, p.281). To Feyerabend, scientists serve as wolves in sheeps’ clothing for many of the political institutions that dominate our society.

In many ways, Feyerabend’s argument is a compelling one. For the case of the 20th and 21st century, government funding often fuels research projects to fulfill larger agendas. In the field of genetics, for example, government funding for the research and implementation of genetically modified crops to increase yields in the agricultural sector cannot be stated as an altruistic motive to progress the scientific sphere (Kidd, 2011). Instead, investing in science leads to a return on investment through boosts in the economy. Where society stands, science is instrumentalized to push a certain agenda. We are far beyond the place in human culture where we are simply just curious--we are curious to achieve a specific goal. This is in turn why Feyerabend pioneered the notion of “epistemological anarchism” (Broad, 1979). To free himself from the “handcuffs” of the scientific method, Feyerabend believes that one derives truth by any means he chooses (Broad, 1979). Therefore, Feyerabend directly attacked the rationality and empiricism of science, and thus challenged those with a reverence for the scientific process.

Yet, Feyerabend’s anarchist perspective on science, too, cannot be separated from the historical contexts of his upbringing. Born in Austria in the early 20th century and inducted in the Nazi army during the 1940s , Feyerabend eventually became a lieutenant by 1944 (Broad, 1979; Preston, 2020). Upon his return to Vienna, he became integrated with many keystone figures of philosophy including Karl Popper (Preston, 2020). This ultimately pivoted the course of

Feyerabend's ideology as he grew "ambivalent towards traditions" in order not to be a cog in a larger political machine (Kent, 2022).

Controversy Surrounding the Grand Canyon: A New View

Throughout the exploration of geology as a science, prior essays have discussed the interconnectedness of religion and scientific inquiry. Based on the power of religious institutions on framing dominant discourse, it is also important to note that this essay will view religion as somewhat of a political system. It wasn't until the 18th century when scientific discovery became somewhat secularized. Yet, religion generally cannot be removed from the scientific and academic spheres, and much overlap still exists in the field today. For higher education systems under the Council for Christian Colleges and Universities (CCCU) for example, approximately 37% of biology professors believe that evolution via natural selection is not the best explanation for biological life (Polanski, 2018). Further, a 2019 study from the Pew Research center found that for when offered three options: 1) humans evolved over time through natural selection 2) humans have evolved over time which was guided by God or a higher power 3) humans have existed in their present form since the beginning of time, 48% of respondents agreed with option 2, and the belief in a higher power (Pew Research, n.d.).

However, it's also important to consider that an individual's religious beliefs may fluctuate over the course of their lifetime. For the case of Tom Vail, a Grand Canyon tour guide, a single interaction with a patron completely pivoted his view on how the landform came to be. As stated on the Canyon Ministries website, an organization founded by Vail, this distinct patron later became his wife, and her presence along the raft tour led Vail to alter his natural, evolutionary perspective in favor of a Biblical narrative (Canyon Ministries, n.d.). In 2003, Vail published his book “The Grand Canyon: A Different View” to synthesize his rationale for his view (Simkin, 2007). This book paired strikingly beautiful images of the Canyon with quotes from the Old Testament. One excerpt from Vail’s work reads as follows:

“The Grand Canyon is not just an icon of beauty. It is a solemn witness to the mighty power of God who is not only the omnipotent creator of all things but also the avenging defender of his own holiness." (Modified from Simkin, 2007).

Vail’s book aligns with the notion of “Flood Geology” reminiscent of the catastrophes from the 19th century. Catastrophism often holds Noah’s flood, induced by God, as responsible force for many geological formations as we know it, including the Grand Canyon (Branch, 2004). Under the notion that the canyon was formed during the Great Deluge, *The Grand Canyon: A Different View* suggests that “the canyon was rapidly cut when the sediment as still soft” and vaguely does not support how the remaining “soft” sediment can stand at such great lengths instead of slumping (Branch, 2004). Further, fossils embedded in the sedimentary rock of the canyon were causalities of the flood (Branch, 2004).

Nonetheless, this book was sold at various bookstore chains as well as the Grand Canyon gift shop (Branch 2004). Even though the gift shop was run by a non-profit organization, the distribution of Vail’s book appeared to be supported by the National Parks Service (Branch, 2004). Therefore, multiple scientific communities such as the American Geological Institute, The American Paleontological Society, the Association of American State Geologists, among others, urged the NPS to act to halt the distribution of Vail’s book for fear it misconstrues the narrative the National Park Service endorses creationism (Branch, 2004).

Within the scientific sphere, many refuted Vail's work by outlining both the flaws of Vail's key argument. For example, Wilson and Beur (2005) highlight the two main issues with Vail's creationist view and the geomorphology of the Grand Canyon: 1) the supposed young age of the earth according to the Bible and 2) the notion that the Grand Canyon's physical form is static and unchanging.

One fallacy in Vail's argument was the acknowledgement of Diabase sills in the canyon, which are estimated to be 841-1249 million years old (Wilson & Beur, 2005). Yet, Vail fails to mention the inconsistencies with the age of the earth of the Bible of 6,000 years, a significant difference in time scales (Wilson & Beur, 2005). To address embedded fossils, Wilson & Beur counter Vail suggestions that species are created in a finished form, and then exterminated by catastrophic flooding events. The absence of intermediate fossils, therefore, does not support the creationist argument based on the logic that the muscle, skin, and feathers of soft-bodied organisms decompose completely therefore they are never found in rock (Wilson & Beur, 2005). In sum, these authors conclude with a key notion, "the creation of the Grand Canyon is a never-ending story rather a footnote in the book of Genesis" (Wilson & Beur, 2005). Taking a subset of a uniformitarianism approach, most geologists in the scientific sphere concur that the natural processes that have shaped the Grand Canyon in the past continue to shape the landmark landform today.

Feyerabend and Religion

As aforementioned, Feyerabend contends that any method to derive the truth is a valid method, this method should not be held to the confines of society. Currently, believing in creationism in STEM related disciplines is the minority opinion, therefore I would infer that

Feyerabend would be in support in regard to Vail's deviation from the status quo. In fact, in *Against Method*, Feyerabend uses Galileo's digression from the church as a key example of how progress occurs when one challenges those with authority (Martin, 2016). Therefore, Feyerabend concurs with other critics of normal sciences such as Kuhn who believed that "science does not proceed according to the normative methods" (Martin, 2016). Therefore, Vail's opposition of authority aligns with Feyerabend's anarchism.

The gray area regarding Feyerabend's support is that in his early work, he aggregated both science and religion as sectors that "force conformity" (Martin, 2016). Therefore, Vail in his creationist view of the Grand Canyon, is in a sense rejecting one tradition for another. However, Feyerabend's later work contends that science is not a singular tradition, but many traditions that are disunified (Martin, 2016). Therefore, his issue with science is mainly the inability to acknowledge that there may be an alternative to a single divine derivation of truth. Contrastingly, during his mid-to-late academic career, Feyerabend view on religion became more sympathetic:

"When I was a student, I revered the sciences and mocked religion and I felt rather grand doing that. Now that I take a closer look at the matter, I am surprised to find how many dignitaries of the church take seriously the superficial arguments I and my friends once used, and how ready they are to reduce their faith accordingly. In this they treat the sciences as if they, too, formed a Church, only a Church of earlier times and with a more primitive philosophy when one still believed in certain results. A look at the history of the sciences, however, shows a very different picture" (Modified from Martin, 2016).

Therefore, Feyerabend ultimately viewed religion as a form of mysticism that fluctuates, compared to a rigid structure of the philosophy of science (Martin, 2016). Since there is no concrete evidence that there is a divine creator, Feyerabend suggests that religion is worth being respected since religion as a whole is a *worldview* not a *theory* (Martin, 2016). A worldview does not have to be true and often cannot be confirmed empirically, thus it simply guides one's behavior and attitudes. Contrastingly, scientific theories present themselves as factual until proven otherwise if the scientific method is followed. In sum, Feyerabend would not advocate for the pulling of Vail's work on from bookstore shelves since political systems such as the government were attempting to homogenize worldviews according to what they believed was correct. Even though I contend that religious institutions are political within themselves, I would argue that they reside in a league of their own since the adherence to church doctrine in modern society is voluntary.

Can religion and science be separate?

The controversy regarding Vail's work highlights that science will never fully be removed from politics. Every individual has biases, whether it was how they were raised or the life experiences they have had. What is the key hinderance in Feyerabend's eyes is that the scientific sphere presents itself as an unbiased infallible discipline. This is similar for political systems—we have laws in place and dominant narratives that should not be deviated from. Conversely, if you do not adhere to the laws, there are consequences. However, a key solution is to acknowledge these biases as a result of the human condition. Since there is no empirical evidence to disprove the notion of God, those who choose to adhere to a religious worldview should not be penalized.

Yet, in the context of geology, I do side with Wilson and Beur (2005) as well as the other geologists who contradict the creationist narrative. According to my worldview, I believe the science that suggests the age of the earth is hundreds of millions of years old. A key distinction, however, is I do not think that Vail's opinion is damaging to be shared. I think it would be hypocritical to attempt to homogenize worldviews when innovation within the scientific sphere has allowed the scientific to progress to such a great extent. I don't believe I have the authority to condemn those outside of my worldview and I think it would be harmful to convince them why they are wrong. One's worldview is ultimately dependent on an individual's own judgment, therefore if someone reads Vail's work and changes their mind the processes of how the earth came to be, I nor a large system should have the authority to try and convince them otherwise.

In other words, I am a large advocate of the secularization of science, but through my education I understand that this is not realistically possible. Even if religion was separate, there would be other confounding variables that would impede science's ability to be completely objective. Therefore, I think that working logically and with acknowledgement of biases is the best middle-ground. Regarding biases in science, May (n.d.) makes an excellent point:

"Instead of merely opting for the conclusion one prefers, human beings curiously come up with reasons, even if dubious ones, in order to justify their decisions to others and, importantly, to themselves."

This process of rationalization is what drives the scientific method. If you have the belief that there is no divine creation, you are going to believe the logic of uniform geological processes spanned diffused across time and space. Contrastingly, if you practice religion, the notion of the Great Deluge for the formation of the Grand Canyon is compelling rationale. To compare the two extremes and condemn one worldview in favor of another is close-minded. Not everyone has to agree all of the time, as long as you feel concrete in your own values.

Conclusion

Feyerabend's critique on the scientific method is a much-needed evaluation on how asserting science that science is completely unbiased is a farce. Science is not purely logic or observation, and thus cannot be separated from historical contexts (Gimbel, 2011, p.281). Any pursuit of knowledge derived from human processes is confounded by biases. How we navigate through these biases is key, but we first have to acknowledge that they exist. Otherwise, the placement of empirical science on a pedestal is no more than the exchange of one tradition for another.

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Essay 7: Reconstructing our Cultural Cognitions Surrounding Science

A New Lens to View Science

The scientific method has a Eurocentric history. Arif Dirlik, a Turkish historian describes Eurocentrism as "...not the result of ignoring others but rather the consequence of organizing the knowledge of the world, including other ways of knowing, into one single systematic whole." (Olarte, 2016). Therefore, it's fair to say that over the past few centuries, scientific discourse has been homogenized. Thomas Kuhn's notion of the paradigm in *The Structure of Scientific Revolution* concurs with this homogeneity of science, by asserting that modern science is "normal science" that is confined by social structures (Layman & Rypel, 2023). The concept of normal science, which Kuhn describes as analogous to "puzzle-solving" since there is predetermined desirable outcome, occurs between revolutionary periods where the status quo changes (Layman & Rypel, 2023). Further, Ruth Hubbard points out in her work *Science, Facts, and Feminism* that most of the dominant discourse of science has been in the control of predominantly white men with privilege, therefore there is a systematic struggle for oppositional views, especially women, to gain traction (Gimbel, 2011, p.294). Additionally, Hubbard regards the making of facts as controlled by "ivory towers" which are "self-reflexive group[s] by the chosen for the chosen." (Gimbel, 2011, p.296).

Thus, how can we integrate various perspectives to break away from western science being the sole solution to answer scientific questions? I argue the scientific method should have a comprehensive approach-- any method derived from logic is a reasonable one. This most closely would represent an aggregation of the semantic, holistic, and critical views of theories. For example, perhaps the best way to answer a scientific problem would be to create a model, perhaps there are already methods put in place that could be followed, and each derivation of a scientific truth should acknowledge inherent biases. Hubbard emphasizes this notion of biases especially, asserting that science cannot be separated from social contexts and that we should be cognizant of our own subjectivity as humans (Gimbel, 2011, p.302). Thus, I suggest a "paradigm shift" in the realm of science to challenge the hierarchical system of science so as not to silence the valuable voices that may have been previously excluded based on gender, race, or culture.

Firstly, this paper will examine an often-overlooked process of learning in our natural world through a case study of Indigenous knowledge. It will further investigate a keystone advocate for Indigenous voices in STEM, Dr. Robin Wall Kimmerer. Moreover, this piece will analyze the strengths of both western and traditional ways of science to propose a call to action for the scientific community to become more inclusive of alternative perspectives as valid methods of science.

Ethnogeology

While many of the greatest philosophers such as Renes Descartes, Isaac Newton, and John Stuart Mill have been educated at some of the most elite western academic institutions and have had their texts continuously published and read by the scientific community, Indigenous knowledge has concurrently been cultivated and distributed in the background. Indigenous knowledge is orally transmitted through the generations, and often based around experiential learning (Fernandez-Llamarazres et al., 2021; Garcia et al., 2020).

Previous essays have evaluated the divide between Catastrophism and Uniformitarianism in the field of geology, which was a predominantly Western debate regarding the role of a divine creator in shaping the natural world as we know it (Leddra, 2010, p.96). Ethnogeologic research proposes an alternative perspective from Indigenous cultural knowledge and how valuable information about our natural world is possible beyond the Eurocentric lens. This highlights that there are more than two competing worldviews of how earth's natural geologic formation came to be (Garcia et al. 2020).

The origin of "ethno-" in science was coined by John P. Harrington in the early 20th century, and the term enthogeologic refers to the "scientific study of people's knowledge and relationships with Earth systems (i.e. with Earth materials, structures, processes, hazards, etc.)" (Garcia et al. 2020). A study by Garcia et al. (2020) examined the relationship between indigenous families in the Dominican Republic and Puerto Rico, as these Caribbean islands are located amidst a karst belt (Garcia et al., 2020). Karst is a calcium carbonate rock formation which represents the dissolution of geologic formations such as stalagmites and stalactites in caverns (Garcia et al., 2020). Survey data suggests that Indigenous respondents framed karstification processes through "metaphors, similes, analogies, stories, and practices" to "describe and interpret noteworthy geological features and processes in karst terrain (Garcia et al., 2020).

In this example, Indigenous knowledge somewhat mimics the process of induction, with knowledge gained by experience and gathered through repeated observations (Garcia et al., 2020). The key distinction is cultural knowledge is not quite as tangible as the common empirical example of induction, the conclusion that "all swans are white" if you see hundreds of white swans (Gimbel, 2011, p.43). Alternatively, cultural knowledge encompasses more abstract viewpoints that integrate emotions and feelings. Further, conceptual key elements (CKE) revealed by the survey found that Indigenous people's described rock formations as a personified process (Garcia et al., 2020). For example, under the notion that rocks are alive, rocks give birth to new rock while a western perspective would describe these processes as weathering and erosion (Garcia et al., 2020). Furthermore, cave art on the walls dating back to 400 CE shows the long-standing generational connection to these formations, thus it is inferred that this knowledge and the means of which it has been described have been transferred within this community for generations (Garcia et al., 2020).

A key takeaway from this case study is that there is no single correct way to describe geologic processes. The Eurocentric explanation of karstification may be the predominant view, but there can be multiple ways to derive the correct conclusion. The only difference between the explanation is through the rhetoric chosen, and we should herald both as scientifically sound explanations. This further emphasizes my proposed view of the scientific method that one should have the freedom to be curious, derive explanations how one sees fit, and acknowledge that another option may exist as not to be close-minded.

Robin Wall Kimmerer and the "Two Ways of Knowing"

I was first exposed to the work of Robin Wall Kimmerer when she visited Gettysburg College campus in the fall of 2022. Robert Wall Kimmerer is a professor of botany at SUNY ESF and has published various works including *Braiding Sweetgrass* to describe the dichotomy between western science and traditional knowledge. Kimmerer writes from her unique perspective as an academic and member of the Citizen Potawatomi Nation (Tonino, 2016). One of her key takeaways is the notion that there are "two ways of knowing" in attempts to bridge this gap between Indigenous and Western knowledge. In an interview with *The Sun*, Kimmerer states:

> "Scientists use the intellect and the senses, usually enhanced by technology. They set spirit and emotion off to the side and bar them from participating. Often science dismisses indigenous knowledge as folklore—not objective or empirical, and thus not valid….The difference is that [Indigenous knowledge] includes spiritual relationships and spiritual explanations. Traditional knowledge brings together the seen and the unseen, whereas Western science says that if we can't measure something, it doesn't exist."

This excerpt highlights many important points that have been discussed in regard to the philosophy of science. Beginning with Aristotle, the initial goal of science was to acquire metaphysical truths of nature using our senses (Gimbel, 2011, p. 8). In modern day, these senses can be extended to technology through the application of modeling (Gimbel, 2011, p.231). Further, in this case, "measuring something" is synonymous with gathering evidence. For the case of deductivists and inductivists, the acquired evidence is empirical (Gimbel, 2011, p.2; Gimbel, 2011, p.56). In terms of hypothetico-deductivism, the sphere began to support the notion of "probabilistic reasoning"-- if we see the same phenomena repeatedly, it is likely true (Gimbel, 2011, p.91). The traditional way of acquiring knowledge is a blend of the aforementioned views, but mostly deals with making observations about the natural world so that we may better understand it and respect it as it deserves. Alternatively, motivation from the Eurocentric lens may be the search for truth to be correct and respected by their peers, as opposed to a reverence towards nature.

Interestingly, Kimmerer's main objection to Western science is this separation between the observer and the natural phenomena during the collection of evidence (Tonino, 2016). I would argue that in the realm of ecology or geosciences, humans are part of the natural world, therefore should not be removed from it. Kimmerer asserts that a traditional perspective celebrates the relationship between the observer and the observed (Tonino, 2016). Thus, Kimmerer concurs with many of the critics of science such as Feyerabend and Hubbard that western science is science is a political game (Gimbel, 2011, p.281). Those with power in society may be pompous and act as if they are not connected to a system, and it becomes an amalgamation of biases in hopes to be the most decorated and the most successful at any cost. When everyone on the individual thinks that they are right, how can the scientific community move forward together?

What should be the scientific method?

The scientific method should always be dependent on context. Do you wish to evaluate how geological wonders such as the Grand Canyon came to be? That is an excellent, curious question, and there are various valid avenues to reach a conclusion. For example, for a first step, there are outlined procedures in the paradigm on geosciences to use isotopic data to date the age of the rock (Earle, n.d.). Follow the methods to analyze the chemical data and derive the conclusion that the age of the geologic landform dates back to millions of years ago. Wondering how erosion may affect this area over time? Maybe you may construct a small-scale model to represent the erosive downcutting of the streambank (Borelli et al, 2021).

Science should not be conducted in a vacuum. Science should be collaborative. An interdisciplinary approach to science appears to be very appealing and a way to integrate various perspectives into the scientific discourse to avoid confirmation biases from like-minded academics. Ultimately, scientific discovery involves humans, therefore why shouldn't we consult one another to see how the hypothesized truth may affect our societies? The notion of collaborative science is not new, as prior research from Bennet and Gadlin (2012) emphasized that the possible success of these collaborative teams, as long as the constituents have common end-goals. High levels of integrated research include regular meetings, various individuals with specific expertise to offer, and strong leadership (Bennet & Gadlin, 2012).

A possible application in the realm of geology would be erosion management in California. Erosive processes in this area, much like many other parts of the world, are a result of a combination of natural processes and human activities such as infrastructure development (Griggs & Patsch, 2019). Thus, humans cannot be separated from this discourse, and whatever quantitative data collected must be applied to our society in some manner. Collected data can empirically describe how satellite data has averaged that sea level rise has averaged 13.1 inches per year since 1993, but what then (Griggs & Patsch, 2019)? Management programs, such as beach nourishment, happen outside of the scientific sphere. Publications regarding the processes of environmental degradation are meaningless without its application, and this application requires the integration of various stakeholders that may interpret this data in different ways. Particularly in the realm of geosciences where humans have altered the environment directly and indirectly, we must further alter nature to a degree that we must further interfere so that we have to derive scientific solutions that are not only effective but are supported by those most affected. Humans cannot be removed from science in this manner, therefore the traditional knowledge of integrating emotions and sentiment into science is of the utmost importance.

Concluding Remarks

Unfortunately, I do not expect the “normal science” that is worshiped in academia to go away anytime soon. It is unrealistic to expect every academic involved in science to throw away tradition that they may have revered for so long and that has been perpetuated in schools. However, I do think that perhaps systematic changes to academia could benefit the scientific community. If we can increase environmental education initiatives to emphasize the role of alternative views on scientific processes, I would expect that as students’ progress through their education that they will consider such a holistic perspective. I personally believe that I have learned so much as I’ve completed my courses in higher education, but I can’t help but wish I was exposed to these types of materials earlier. Further, I think Kimmerer’s notion of “two ways of knowing” is particularly powerful, to highlight the divide between Eurocentric and traditional processes of science. In reality, there are more than just two ways of knowing. However, being able to think critically and sieve through all relevant information to derive a conclusion that one can support based on their own values is how I believe that science should progress.

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