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ANCIENT GREEK SCIENTISTS (600 B.C. - 600 A.D.) ON THE CONCEPTS OF SPACE AND TIME: A GEOGRAPHICAL APPROACH BASED ON BIOGRAPHIES

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Abstract

This paper explores the diverse landscape of ancient Greek scientists between 600 B.C. and 600 A.D. who significantly contributed to the understanding of space and time. Focusing on the biographies of ancient engineers, this research examines the inventors of tools for measuring time and distances, creators of maps and clocks, as well as philosophers who explored the conceptual realms of space and time. Employing a geographical approach, we meticulously cluster these eminent figures into maps based on various criteria such as periods, scientific fields, and additional classifications including social and historical conditions, and supplementary professions. This spatial-temporal clustering allows for a nuanced examination of the interconnected evolution of ideas and innovations across different eras and scientific domains. The exploration encompasses diverse periods, spanning from the pre-Socratic era to the Hellenistic period and into the early Byzantine era. Each cluster unveils the intricate web of influences, collaborations, and individual pursuits that shaped the ancient Greek scientific landscape. By synthesizing data from biographical sources, historical records, and philosophical treatises, we gain a comprehensive understanding of the contextual factors that influenced the conceptualization and application of space and time-related instruments. This research not only sheds light on the scientific achievements of these ancient engineers but also provides insights into the socio-cultural and historical conditions that nurtured their intellectual pursuits. By examining the geographical contexts within which these scientists operated, we discern patterns and connections that contribute to a more holistic understanding of ancient Greek technology. Our findings offer a valuable resource for scholars and academics interested in the biographies of ancient Greek scientists, enriching the broader narrative of scientific progress in the above-mentioned period.

Keywords: space, time, ancient Greek scientists, biographies

1 Introduction

From 600 B.C. to 600 A.D., ancient Greece went through a transformative period that significantly contributed to the scientific fields of physics, philosophy, and mathematics. This era was marked by intense intellectual exploration and witnessed the emergence of multi-scientists who sought to unravel the mysteries of the universe through empirical observation and systematic philosophical argumentation. Some of the central concepts to their inquiries were the concepts

of space and time, explored not only as abstract philosophical concepts, but also through practical technological innovations such as the Antikythera Mechanism (Figure 1) and ancient Greek sundials (Figure 2), which laid the path for modern engineering. This research examines the contributions of ancient Greek scientists to these concepts, utilizing a geographical approach that correlates their innovations within the Greek intellectual history, highlighting how specific regions and intellectual hubs, such as Athens and Alexandria, influenced the development and dissemination of scientific ideas.

The intellectual journey of ancient Greek thinkers began with the pre-Socratics, most notably Anaximander, who initiated the intellectual shift from mythological explanations of the universe to more systematic, rational approaches. The understanding of space and time was further advanced by subsequent philosophers and mathematicians, mostly Pythagoras, whose famous theorem provided a crucial mathematical tool for understanding spatial relationships and became a cornerstone of geometric theory (Faure, Valli, & Zucker, 2022).¹ The progression of Greek scientific thought, particularly in the field of astronomy, was markedly influenced by later figures such as Hipparchus, whose systematic approach to celestial mapping and the development of trigonometry enabled more accurate predictions of astronomical events (Sattler, 2020; Berggren, 2000).²

In addition to their theoretical contributions, Greek thinkers also excelled in the practical application of their scientific knowledge. The works of engineers like Hero of Alexandria, who created sophisticated mechanical devices, demonstrate the dynamic interplay between theoretical physics and practical engineering in ancient Greek culture. Hero's inventions, such as the aeolipile, an early form of a steam engine, not only addressed immediate practical needs but also embodied the application of mathematical principles to solving real-world problems (Coulton, 1999). These inventions, commonly found in temples and other communal areas, demonstrate the Greeks' skill in combining scientific exploration with everyday life and religious rituals, emphasizing the combination of theory and practical use that was a defining element in Greek science. Hero's accomplishments showcase the zenith of Greek engineering skills and establish a clear connection between Greek scientific progress and future technological developments made by the Romans.

The philosophical exploration of time also deepened with the Stoics, who contributed to the philosophical examination of time, by introducing the idea of time as a continuous flow, which had a lasting impact on later discussions about its nature (Jacob, 1996). The Stoic perception of time as linear and deterministic differed greatly from previous ideas, marking a change in Greek philosophy towards a more organized perception of the universe's progression and its impact on human existence. This philosophical maturation was followed by developments in metaphysical thought, particularly by Neoplatonists such as Plotinus, who posited a more integrated view of time and space as interconnected dimensions of the cosmos (Sattler, 2020).³ Plotinus' philosophy, which sought to reconcile the material and the immaterial, offered a sophisticated model in which time and space were not only physical dimensions but also had profound metaphysical implications, influencing subsequent Christian and Islamic thought.

Moreover, the advancement of Greek mathematics, especially through geometry, was essential in the perception of space. Euclid's *Elements* presented a comprehensive compilation

¹ Faure, R., Valli, S.-P., & Zucker, A., 2022. *Conceptions of Time in Greek and Roman Antiquity*: Walter de Gruyter. This discussion provides a holistic view of Pythagoras's theorem and emphasizes its foundational role in geometric theory and the belief in cosmic harmony.

² Sattler, B. M. (2020); Berggren, J. L. (2000). *Episodes in the Mathematics of Medieval Islam*. Springer Science & Business Media. These sources analyze Hipparchus's advancements in trigonometry and celestial mapping, that resulted in establishing systematic observational techniques and influenced later astronomical scientists, such as Ptolemy.

³ Sattler, B. M., 2020. *The Concept of Motion in Ancient Greek Thought: Foundations in Logic, Method, and Mathematics*: Cambridge University Press. Sattler shows Plotinus's aspect of time and space into a unified metaphysical framework, which ended up reflecting Neoplatonist views on the interconnectedness of physical and spiritual worlds.

of the knowledge of geometry during that era, arranging the basic principles that would influence spatial reasoning for many years to come. (Hill, 2013). Euclid's work not only impacted Greek mathematicians but also set the basis for contemporary geometry, as his axiomatic approach laid a strong foundation for theoretical studies and practical uses in areas like architecture and astronomy. Euclid's *Elements* had a significant impact on educational systems in the Hellenistic world and during the medieval era, establishing itself as a fundamental basis for the study of mathematics in the Islamic world and Renaissance Europe.

This analysis of the contributions of ancient Greeks to the comprehension of space and time emphasizes the notable progress achieved during that period and places these accomplishments in a wider geographical and historical framework. This research aims to illuminate the ways in which Greek scientific thought, as well as the contributions of figures like Anaximander, Pythagoras, Euclid, and Hero of Alexandria, have influenced Western scientific development by examining their lives and works. The geographical perspective examines the ways in which various regions in the Greek world influenced the spread of knowledge, leading to a deeper understanding of the evolution, dissemination, and improvement of ideas.

The long-lasting impact of these philosophers can be seen in the widespread distribution and long-term effect of their ideas, which defined the intellectual landscape of the ancient Mediterranean region and established the basic models that would influence scientific research for many years. The combination of real-world observation, using math and argumentation, defined Greek science and influenced the progress of Western science, keeping the insights of these ancient philosophers valuable in modern times.

The structure of this research paper begins with the Literature Review section, which aims to provide the necessary background and places this study within the broader academic conversation. In the next section, Methodology gives all the necessary information explaining how the research was conducted and which methods were chosen. Moving on, the Results section presents the findings of the research, providing the data that will be interpreted in the next section, the Discussion, to draw conclusions. There, the author correlates findings to existing literature, exploring their implications and limitations, and also suggesting directions for future research. Finally, in the Conclusion section, final thoughts are shared, while summarizing the key findings of the research.

2 Literature Review

This part of the research seeks to give a thorough summary of the subject and also emphasizes initially the historical context of space and time in ancient Greek philosophy, and then the effects of technological advancements and geography on scientific progress, alongside the importance of cross-disciplinary methods, in fully comprehending these ideas. This review will analyze existing research to identify gaps and set the stage for a study that explores the connection between technological innovation and philosophical thought in ancient Greece.

2.1 Historical Background of Space and Time in Ancient Greek Thought

The ancient Greek exploration of space and time is deeply connected to the mythological and cosmological beliefs of their early culture. The early writings of Hesiod and Homer blend space, time, the divine, and natural world in their cosmology, showing a pre-philosophical perspective that was later organized by pre-Socratic philosophers. For example, in Hesiod's *Theogony*, there is a genealogy of the gods that also acts as a cosmogony, placing the birth of the universe within a time period controlled by divine powers. Hesiod, in *Theogony*, mentions the creation of Chaos followed by Gaia and Tartarus, representing the connection of space and divine origins in the early Greek beliefs.⁴

⁴ Hesiod. (ed.) 2008. *Theogony*. In M. L. West, *Hesiod: Theogony, Works and Days*, Shield:

As Greek philosophy progressed, thinkers such as Anaximander approached more abstract and logical understandings of space and time, moving away from relying on mythological explanations. Sattler (2020) discussed Anaximander's idea of the *apeiron*, which presented an early interpretation of the infinite, questioning the conventional limits of the cosmos set by ancient mythological beliefs. Anaximander is credited for saying, "The principle of all things is the *apeiron*...from where things take their rise, there they return once more, as is ordained; for they pay penalty and retribution to each other for their injustice according to the assessment of Time" (Fragment 1, DK 12A9).⁵ This concept of the *apeiron* as an unlimited principle (Aristotle, *Physics*, 203b)⁶ set the foundation for future philosophical inquiries by thinkers like Heraclitus and Parmenides, who expanded on notions of change, eternity, and the essence of existence.

Pythagoras and his followers, known for integrating mathematical concepts into philosophy, greatly enhanced the comprehension of space by focusing on numerical connections and geometric shapes. According to Huffman (1993)⁷, the Pythagorean theorem not only explains the sides of an orthogonal triangle but also speaks to the universe's natural order and harmony. Iamblichus claimed that Pythagoras believed "Number controls shapes and concepts, and is the origin of deities and spirits" (Life of Pythagoras, 29). In Pythagorean philosophy, it was believed that understanding the structure of the universe required a strong grasp of numbers, emphasizing the close connection between mathematics and cosmology. Pythagoras' efforts established the groundwork for a mathematical understanding of space, which subtly impacted the cosmologies of Plato and Aristotle.

2.2 Technological Innovations and Their Influence on Philosophical Thought

Studying the intersection of technological innovation and philosophical thought in ancient Greece reveals how practical inventions and empirical observations impacted abstract concepts such as space and time. One of these inventions, the Antikythera Mechanism (Figure 1), that considered the world's first analog computer, is a major technological accomplishment of the ancient Greeks. This complex tool, employed for forecasting astronomical positions and eclipses for calendar and astrology reasons, demonstrates the advanced comprehension of celestial mechanics in ancient Greece. According to Freeth et al. (2006),⁸ the Antikythera Mechanism (Figure 1) illustrates the high level of Greek scientific advancement, where technological progress connected to philosophical explorations of the universe.

Oxford University Press, pp. 116-119. This passage shows the early Greek conception of space and time as being interconnected with the origins of the cosmos.

⁵ Anaximander. Fragment 1, DK 12A9. This excerpt is one of the limited sources that can be directly linked to Anaximander, showcasing his idea of the *apeiron* and its role in the natural order.

⁶ Aristotle. *Physics*. 203b. Aristotle contemplates Anaximander's groundbreaking concept of the infinite, making a transition from mythological explanations of the universe to a more theoretical and philosophical comprehension.

⁷ Huffman, C. A., 1993. *Philolaus of Croton: Pythagorean and Presocratic*: Cambridge University Press. Huffman, investigates Pythagoras's philosophical and mathematical contributions, with a particular emphasis on the influence of the Pythagorean theorem on Greek cosmology and the broader intellectual tradition.

⁸ Freeth, T., Jones, A., Steele, J., & Bitsakis, Y., 2006. Decoding the Antikythera Mechanism: *Science: Nature*, 444(7119), pp. 587-591. Freeth et al. offer an in-depth technical examination of the Antikythera Mechanism (Figure 1), emphasizing its significance in ancient Greek astronomy and its importance for comprehending the technological advancements of that era.

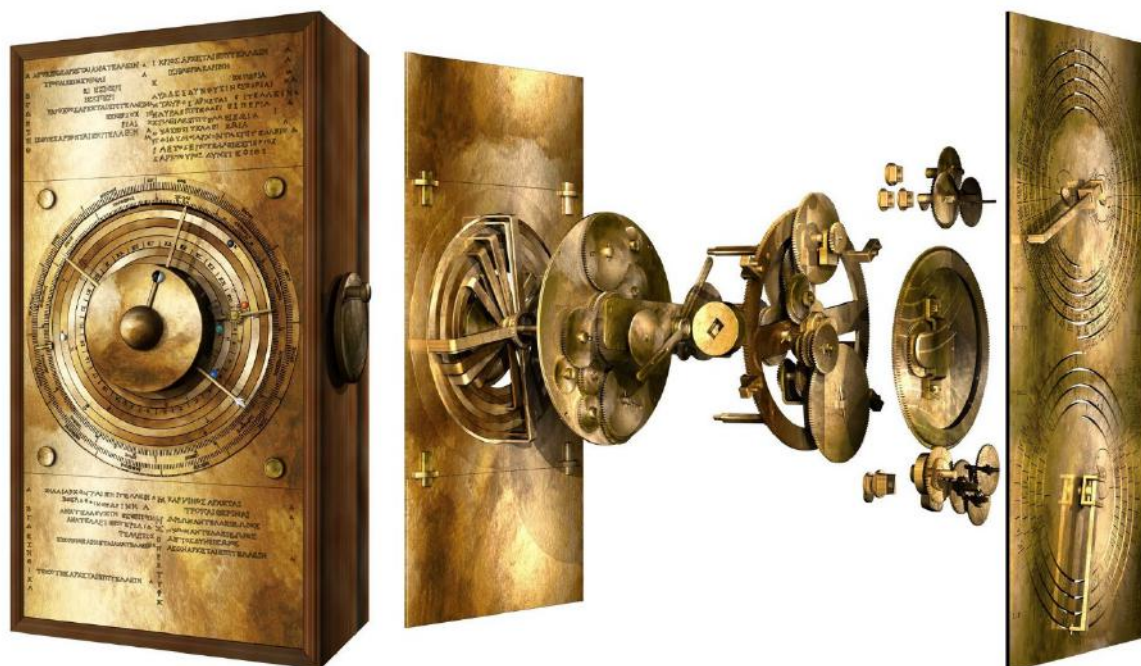


Figure 1: Turner, B., 2022. *The Antikythera Mechanism*. <https://www.livescience.com/antikythera-mechanism-worlds-first-computer-modeled.html> [visited at 02/09/2024].

In a similar manner, the development of instruments such as sundials and water clocks played a crucial role in forming the Greek concept of time. The *gnomon*, a precursor to ancient sundials, was useful for tracking time and also initiated philosophical discussions on the nature of time. Thibodeau (2017)⁹ examines how Anaximander used the *gnomon* (Figure 2) to combine empirical observation with philosophical inquiry, showcasing the efforts of early Greek thinkers. Herodotus mentions the *gnomon* (Figure 2) in his *Histories*: "They [the Babylonians] were the first to divide the day into twelve hours, and they also introduced the use of the *gnomon* (Figure 2), the sundial, and the twelve parts of the day" (*Histories*, II.109).¹⁰ Not only were these developments used for measuring purposes, but they also influenced the Greeks' understanding of the cosmos and their place within it. The literature emphasizes the significance of these devices in shaping Greek concepts of time and change.

⁹ Thibodeau, P., 2017. Anaximander's Spartan Sundial and the Geographical Revolution: *American Journal of Archaeology*, 121(3), pp. 431-458. Thibodeau studies how Anaximander created the *gnomon* (Figure 2) and how useful it was in early Greek astronomy.

¹⁰ Herodotus. *The Histories* [English translation of: Waterfield, R. 2008. *Herodotus The Histories*: Oxford University Press]. Herodotus describes the early use of the *gnomon* (Figure 2) and its significance in ancient timekeeping traditions.



Figure 2: West, D., 2024. A sundial. The gnomon is the part that casts the shadow. <https://owlcation.com/humanities/The-Ancient-Greek-Philosopher-Anaximander-of-Miletus> [visited at 02/09/2024].

The literature also explores how these technological advancements were disseminated throughout the Greek world and beyond. The transmission of Greek culture after the conquests of Alexander the Great encouraged the interchange of scientific and philosophical concepts throughout the Mediterranean and Near East. Cuomo (2007) provides evidence of the widespread impact of Greek innovations on the advancement of science and technology in ancient civilizations, as they were adopted and modified by other cultures. The cross-cultural exchanges improved the complexity of Greek technology and also guaranteed its continuation in subsequent scientific traditions, such as those of the Medieval Europe and Islamic civilization.

2.3 Philosophical Contributions by Key Thinkers

The philosophical contributions of prominent philosophers such as Anaximander, Pythagoras, and Aristotle have been thoroughly examined in the literature, with each individual offering distinctive perspectives on the concepts of space and time. One of the earliest attempts to conceptualize the infinite, Anaximander's introduction of the *apeiron*, as illustrated in Table 1, has been widely acknowledged as a pivotal moment in the history of Greek philosophy. The ideas of Anaximander, as Sattler (2020) observes, established the foundation for subsequent philosophical investigations of the infinite and the eternal, influencing not only his immediate successors but also later philosophers such as Plato and Aristotle.

On the other hand, Pythagoras is most renowned for his contributions to mathematics; however, he and his followers also made impactful contributions to the philosophical comprehension of space and time. The Pythagorean belief in the harmony of the cosmos, as investigated by Huffman (1993), is indicative of a profound connection between the structure of the universe and mathematical order, as illustrated in Table 1. The Pythagorean concept of a

harmonious cosmos was crucial in the formation of the Greek comprehension of celestial mechanics, particularly in the field of astronomy, where it influenced later developments in both philosophy and science.

Numerous studies have been conducted on Aristotle's contributions, particularly in his *Metaphysics* and *Physics*. Aristotle's concept of space (*topos*) as the "place" of an object and his comprehension of time as a measure of change in relation to before and after represents a substantial departure from the perspectives of his predecessors. Aristotle writes, "Time is the number of movement in respect of 'before' and 'after'" (*Physics*, IV.11, 219b1).¹¹ This definition reflects Aristotle's systematic approach to understanding the natural world through empirical observation. According to Lang (1992), Aristotle's conceptualization of space and time was indicative of his dedication to understand the natural world through reason and evidence. His work had an impact on the thought process of both the medieval and early modern periods.

The following table offers a comparative overview of the main ideas of ancient Greek philosophers in order to gain a more comprehensive understanding of the various approaches to the concepts of space and time.

Table 1. Comparison of Philosophical Approaches to Space and Time

Philosopher	Focus on Space	Focus on Time
Anaximander	Introduced the concept of the <i>apeiron</i> (infinite)	Introduced early notions of the infinite cycle of time
Pythagoras	Emphasized numerical harmony in spatial relationships	Linked mathematical harmony with temporal cycles
Parmenides	Argued that space (being) is unchanging and eternal	Claimed time as an illusion; true reality is timeless
Heraclitus	Space is in constant flux	Famous for the idea that "time is like a river" – everything is in constant flow
Plato	The cosmos is an ordered, spatial structure, reflecting the realm of forms	Time as the "moving image of eternity," connected to the eternal forms
Aristotle	Defined space (<i>topos</i>) as the "place" of an object	Defined time as a measure of change concerning 'before' and 'after'

This comparative analysis highlights the diversity of thought in ancient Greek philosophy, demonstrating how different thinkers approached the complex notions of space and time. By examining these varied perspectives, we can acquire a profound understanding of how these fundamental concepts developed and influenced upcoming scientific and philosophical advancements.

2.4 Impact of Geography on the Development of Scientific Thought

The ideas of space and time were significantly influenced by the geographical context in which Greek scientific thought developed. In particular, the city-states of Miletus, Athens, and Alexandria were critical hubs of intellectual activity, where philosophical and scientific concepts

¹¹ Aristotle. *Physics* [English translation of: R. P. Hardie & R. K. Gaye. 1984. In *The Complete Works of Aristotle*, Vol. 1, pp. 315-446: Princeton University Press.] Aristotle's definition of time as a way to quantify alterations is a fundamental aspect of his philosophy of nature.

were developed and exchanged. Miletus, often regarded as the birthplace of Greek philosophy, was home to the Milesian school of thought, which included figures such as Thales, Anaximander, and Anaximenes. These thinkers laid the foundation for the systematic study of nature, which would later be expanded upon by philosophers in Athens and Alexandria.

During the Classical period, Athens was the center of philosophical study, as it was the intellectual hub of ancient Greece. Plato's Academy and Aristotle's Lyceum, were established institutional frameworks for the systematic study of science and philosophy. Burnet (1908) observes that the high concentration of intellectual activity in Athens facilitated the development of sophisticated theories of space and time, which were subsequently disseminated throughout the Hellenistic world.

Alexandria, founded by Alexander the Great, became a major center of learning during the Hellenistic period. The Library of Alexandria, as discussed by Fraser (1972), was a hub of scientific and philosophical research, attracting scholars from across the Mediterranean. The city's strategic location and its status as a meeting point of cultures made it an ideal environment for the exchange of ideas. The development of scientific thought in the ancient world was significantly influenced by the works generated in Alexandria, particularly in the fields of astronomy and mathematics.

The literature emphasizes the extent to which the geographical dissemination of Greek ideas, particularly in the aftermath of Alexander the Great's conquests, facilitated the dissemination of these concepts throughout the Mediterranean and Near East. This cultural exchange not only enhanced the scientific traditions of other civilizations but also guaranteed the preservation and transmission of Greek knowledge to following generations. Studies such as those by Lewis (2002)¹² have examined the role of geographic and cultural factors in the preservation and transmission of Greek scientific knowledge, which emphasize their significance in the broader narrative of intellectual history.

2.5 Interdisciplinary Approaches in Understanding Ancient Greek Thought

Interdisciplinary studies that combine literature, philosophy, science, and technology have provided valuable insights into the understanding of ancient Greek concepts of space and time. The integration of these disciplines enables a more in-depth examination of ancient texts, artifacts, and ideas, thereby revealing the interrelation of various aspects of Greek thought.

Recent studies have stressed out the importance of considering technological artifacts, such as the Antikythera Mechanism (Figure 1), in the context of philosophical discussions about space and time. These artifacts are not only practical tools, according to scholars like Netz and Noel (2007); rather, they are essential in the philosophical and scientific frameworks of their era. Researchers can develop a deeper understanding of the evolution and interaction of these ideas by analyzing the technological innovations of the ancient Greeks in conjunction with their philosophical writings.

Additionally, cross-disciplinary methods have emphasized the importance of geography in influencing scientific thinking. Fraser (1972) highlights the significance of taking into account the wider cultural and geographical background in which concepts were formulated, through the interaction of ideas across diverse regions. This method allows for a deeper comprehension of ancient Greek beliefs and offers a more detailed view of how science and philosophy evolved in ancient times.

2.6 Identification of Gaps in the Literature

Despite the extensive study on space and time in ancient Greek thought, there are still numerous areas that have yet to be explored . One significant gap is the relationship between technological

¹² Lewis, E. V., 2002. *The Intellectual Legacy of Alexander the Great*: Routledge. Lewis, investigates how Greek scientific knowledge spread geographically after Alexander's conquests.

innovation and philosophical thought. Although there has been broad research on the individual contributions of philosophers and scientists, the extent to which technological advancements influenced these ideas has not been thoroughly investigated. This study aims to address this gap by examining how technological artifacts were integrated into Greek philosophical frameworks and their influence on the development of concepts of space and time.

Another area that requires further analysis is the role of geography in the dissemination of scientific ideas. Although the importance of centers like Athens and Alexandria has been well-documented, additional research is needed to interpret the manner in which ideas were disseminated across various regions and the ways in which local contexts impacted the evolution of scientific thought.

In conclusion, the literary works on the concepts of space and time in ancient Greek thought provide a rich and complex picture of the development and appreciation of these concepts. The objective of this research is to contribute to a further understanding of the relationship between technology and philosophy in ancient Greece, offering new insights into the ways in which these ideas were developed, disseminated, and preserved.

3 Methodology

3.1 Research Design

This research employs a historical-analytical framework to investigate the contributions of ancient Greek scientists to the understanding of space and time from 600 B.C. to 600 A.D. This approach integrates qualitative and quantitative methods, allowing for a thorough examination of how geographical, social, and intellectual factors influenced the development and spread of scientific ideas.

The research is guided by key questions, including: How did ancient Greek scientists conceptualize space and time? What were the main factors that shaped their scientific approach? How did geographical factors, such as the locations of key intellectual centers, impact the distribution and advancement of these concepts? This methodology is particularly suited to exploring how scientific ideas evolved over time within the cultural and intellectual landscape of ancient Greece.

3.2 Data Collection

The primary data sources concentrate on classical texts composed by ancient historians, philosophers, and scientists, including Herodotus, Thucydides, Plato, Aristotle, and Euclid. These texts are accessed through digital archives and physical collections, with a focus on accurate translation and interpretation. The study includes lesser-known fragments that offer additional perspectives into the diversity of ancient Greek scientific thought.

A thorough review of secondary sources is comprised, including scholarly articles, biographies, and historiographical studies. These sources are accessed through academic databases like JSTOR and Project MUSE, thereby guaranteeing that the research is updated by the most recent literature. The study is positioned within the broader academic framework and the gaps that this research seeks to address are identified through the use of secondary sources.

Archival visits to key institutions, such as the NOESIS - Science Center & Technology Museum in Thessaloniki, are conducted to directly study and examine artifacts and manuscripts. Archaeological data, especially regarding scientific tools and technological objects, is combined to offer concrete proof of the progress made in ancient Greek technology.

3.3 Techniques of Analysis

The qualitative analysis implements thematic and discourse analysis to identify and explore key themes related to space and time in the primary sources. This analysis reveals the underlying

philosophical assumptions and rhetorical strategies that structured ancient Greek scientific thought.

Quantitative analysis is done by utilizing Geographic Information Systems (GIS) to map the spatial distribution of scientific activity throughout ancient Greece. This examination detects patterns in the dissemination of scientific ideas and examines how the proximity to intellectual hubs affects the transmission of information. Also, statistical techniques are employed for examining the occurrence and spread of scientific ideas in publications, offering a more comprehensive view of their influence.

The combination of qualitative and quantitative methods allows for a correlational analysis of ancient Greek scientific thought. By integrating these approaches, the study captures both the depth of individual contributions and the wider geographical and cultural contexts in which these ideas developed.

3.4 Research Framework

The research is based on a socio-historical theoretical framework that underscores the influence of political dynamics, cultural norms, and social structures on scientific thought. This framework combines theories from sociology, anthropology, and the history of science, to offer a multi-faceted perspective on understanding the evolution of scientific concepts.

This framework helps to understand how factors such as social hierarchy, political power, and cultural exchange influenced the production and dissemination of knowledge in ancient Greece. The analysis also evaluates the influence of external factors, such as war and commerce, patronage, and institutional support, on scientific inquiry.

The case study approach addresses on prominent figures such as Anaximander, Pythagoras, Euclid, Hipparchus, and Hero of Alexandria. These scientists are chosen based on the availability of comprehensive historical data regarding their work and impact, as well as their substantial contributions to the understanding of space and time. The life, contributions, and broader impact of the scientist's ideas on the following generations are all thoroughly examined in each case study. This examination underscores the diversity of thought that existed within the ancient Greek science community and traces the development of key concepts over time.

Geographical analysis is central to this research, focusing on the spatial aspects of scientific progress in ancient Greece. GIS mapping is used to create visual representations of the intellectual networks and to analyze how geographical factors impacted the spread of scientific ideas. This method elucidates the physical and cultural routes that facilitated the exchange and development of scientific knowledge, demonstrating how certain cities and regions emerged as innovation hubs.

The study utilizes techniques from various fields like history, philosophy, archaeology, and geography to offer a holistic view of ancient Greek scientific ideas. Archaeological interpretation investigates the material culture associated with scientific practices, while philosophical analysis is employed to interpret the theoretical foundations of ancient Greek science. This cross-disciplinary method ensures a thorough grasp of the origins and dissemination of these concepts throughout various areas and eras.

The research is conducted in accordance with rigorous ethical standards, particularly in the handling of sensitive historical documents and antiquities. Permissions are obtained for the use of copyrighted materials, and all sources are cited appropriately. The analysis acknowledges the contributions of contemporary scholars, ensuring that the intellectual property rights of these scholars are respected.

The methodology recognizes its limitations, such as the difficulties associated with accurately mapping primordial data and the potential biases in historical interpretation. The selection of case studies, despite its focus, may not fully represent the range of ancient Greek scientific ideas, as some significant contributions are not well depicted due to the lack of surviving records.

Furthermore, the precision of GIS analysis is contingent on the availability of reliable historical maps and data.

4 Results

4.1 Distribution of Scientists in the concepts of space and time

This research carefully documented the distribution of space and time ideas of ancient Greek scientists from 600 B.C. to 600 A.D., revealing substantial activity clusters in key regions and periods. The results are organized in chronological order to demonstrate the evolution of scientific thought over time and across various locations.

4.1.1 Pre-Socratic Period (600 B.C. - 450 B.C.)

In this pivotal period, Miletus and Samos became vibrant centers of intellectual activity. Figures like Thales, Anaximander, and Pythagoras established fundamental concepts that transitioned from mythological to rational explanations of natural phenomena.

- **Thales of Miletus** is acknowledged as the first Greek philosopher to suggest that "water is the principle, or the essence, of all things," a departure from mythological narratives that established a methodological approach based on observation and reasoning (Aristotle, *Metaphysics*, 983b20-24). Thales's approach of deriving principles from observable phenomena set the stage for the subsequent naturalistic and scientific inquiries.¹³
- **Anaximander** proposed the idea of the *apeiron*, an endless, limitless substance that he believed was the source of all things. This concept broadened the range of philosophical investigation from the physical aspects to the theoretical and boundless, impacting subsequent investigations into metaphysics (Simplicius, *Commentary on Aristotle's Physics*, 24.13-25).¹⁴ Anaximander's contributions also extended to early geography, as he is credited with creating one of the earliest maps of the known world, exhibiting his overall interest in spatial science. Anaximander's introduction of the *apeiron* (the infinite) and his innovations in cartography and time measurement demonstrate the early Greek tendency to merge practical observation with theoretical analysis (Aristotle, *Physics*, 203b).
- **Pythagoras of Samos** made a substantial contribution to the integration of mathematics and philosophy. In addition to revolutionizing mathematics, his formulation of the Pythagorean theorem also proposed that the structure of reality is underpinned by numerical relationships (Iamblichus, *Life of Pythagoras*, 256). Pythagoras's conviction that "number is the ruler of forms and ideas" reflected the deep connection between mathematics, music, and cosmology, impacting future advancements in these domains.¹⁵

4.1.2 Classical Period (450 B.C. - 323 B.C.)

Athens emerged as the center of intellectualism in Greece, where renowned thinkers such as Plato and Aristotle elaborated on and advanced existing concepts to construct sophisticated models of the cosmos and natural philosophy.

- **Plato** in his *Timaeus* presented a cosmology that merged geometry and philosophy, suggesting that the universe was created by a divine artisan based on eternal forms. This perspective considered the cosmos to be a living entity with a consciousness, organized in accordance with

¹³ Thales's impact also reached other Pre-Socratic philosophers, like Anaximenes, who suggested air as the primary element, and Heraclitus, who stressed the oneness of contradictions.

¹⁴ Anaximander's *apeiron* brought the idea of endlessness into Greek philosophy, broadening the range of philosophical contemplation and impacting later cosmological ideas, including those of Anaxagoras and Empedocles.

¹⁵ The Pythagorean belief in the harmony of the spheres, which posited that the distances between planets were equivalent to musical intervals, is indicative of the profound relationship between mathematics and cosmology in Greek thought.

geometric principles (Plato, *Timaeus*, 28a-c).¹⁶ Plato's ideas profoundly influenced later Neoplatonic thought and the development of Christian cosmology.

- **Aristotle** provided a thorough examination of space and time in his works, particularly in *Physics*. He described space (*topos*) as the "place" of an object and time as "the number of movements in respect of 'before' and 'after,'" guiding philosophical studies over time (Aristotle, *Physics*, IV.220a24-30).¹⁷ Aristotle's emphasis on empirical observation and systematic categorization of natural phenomena was a crucial change towards a more scientific method, influencing succeeding thinkers in different fields, such as Theophrastus and Strabo.¹⁸
- **Eudoxus of Cnidus** made a major contribution to the geometric modeling of the cosmos, especially with his theory of concentric spheres. According to his theory, the skies consisted of multiple rotating spheres, each carrying a planet, offering the first detailed geometric explanation of planetary movements (Heath, *A History of Greek Mathematics*, Vol 1). This model was essential in the progress of Greek astronomy and was later included in the writings of Aristotle and Ptolemy.

4.1.3 Hellenistic Period (323 B.C. - 31 B.C.)

During the Hellenistic era, scientific and mathematical progress flourished due to the blending of Greek, Egyptian, and other Near Eastern societies, mainly in Alexandria.

- **Euclid**, through his *Elements*, organized geometric knowledge into an axiomatic framework which continues to influence mathematics. His contributions led to the development of the precise mathematical description of space, impacting fields like architecture and astronomy (Euclid, *Elements*, Book 1). *Elements'* logical framework established the foundations for contemporary mathematical logic and the scientific method, influencing both ancient and later scholars.
- **Archimedes of Syracuse** employed principles of geometry to understand forces, resulting in the creation of machines such as levers, pulleys, and the Archimedean hydraulic clock. These inventions demonstrated the practical application of mathematical axioms to conceive real-world phenomena (Archimedes, *On the Equilibrium of Planes*, 1.6-7). Archimedes' work in hydrostatics, particularly his principle that a body sank in a fluid experiences a buoyant force equal to the weight of the displaced fluid, was a groundbreaking contribution that laid the foundations for fluid mechanics.
- **Hipparchus of Nicaea**, frequently referred to as the father of trigonometry and based in Rhodes, made groundbreaking contributions to the field of astronomy, such as identifying the precession of the equinoxes with impressive accuracy (Ptolemy, *Almagest*, III.1). His development of trigonometric techniques allowed for more accurate calculations of celestial phenomena, which was crucial for the progress of astronomy. Hipparchus's star catalog, documenting the coordinates of more than a thousand stars, was a great achievement that served as a guide for future astronomers, including Ptolemy.

4.1.4 Roman and Early Byzantine Period (31 B.C. - 600 A.D.)

The period was characterized by the integration of Roman practicality with Greek scientific thought, which resulted in the advancement of technology and science.

- **Ptolemy**, based in Alexandria, combined and elaborated on Hipparchus's astronomical research in his *Almagest*, which introduced a detailed geocentric system (Figure 3) that was widely accepted up to the Renaissance (Ptolemy, *Almagest*, introduction). Ptolemy's *Geographia* also included a precise mapping of the known world, combining spatial information with observations of celestial bodies. His contributions were fundamental for navigation and cosmology until the time of the Copernican Revolution.

¹⁶ Plato's cosmological dialogue *Timaeus* displays the philosophical integration of geometry with the universe's creation, reflecting deep Pythagorean influences and the concept that the cosmos is a rational and orderly entity.

¹⁷ Aristotle's definitions of space and time in his *Physics* provided a conceptual basis that impacted generations of philosophical and scientific thinking, especially during the Islamic Golden Age and the European Middle Ages.

¹⁸ Theophrastus, a student of Aristotle, further developed the empirical study of natural phenomena, particularly in botany and mineralogy, while Strabo's geographical research upheld the practice of integrating empirical observation with philosophical investigation.

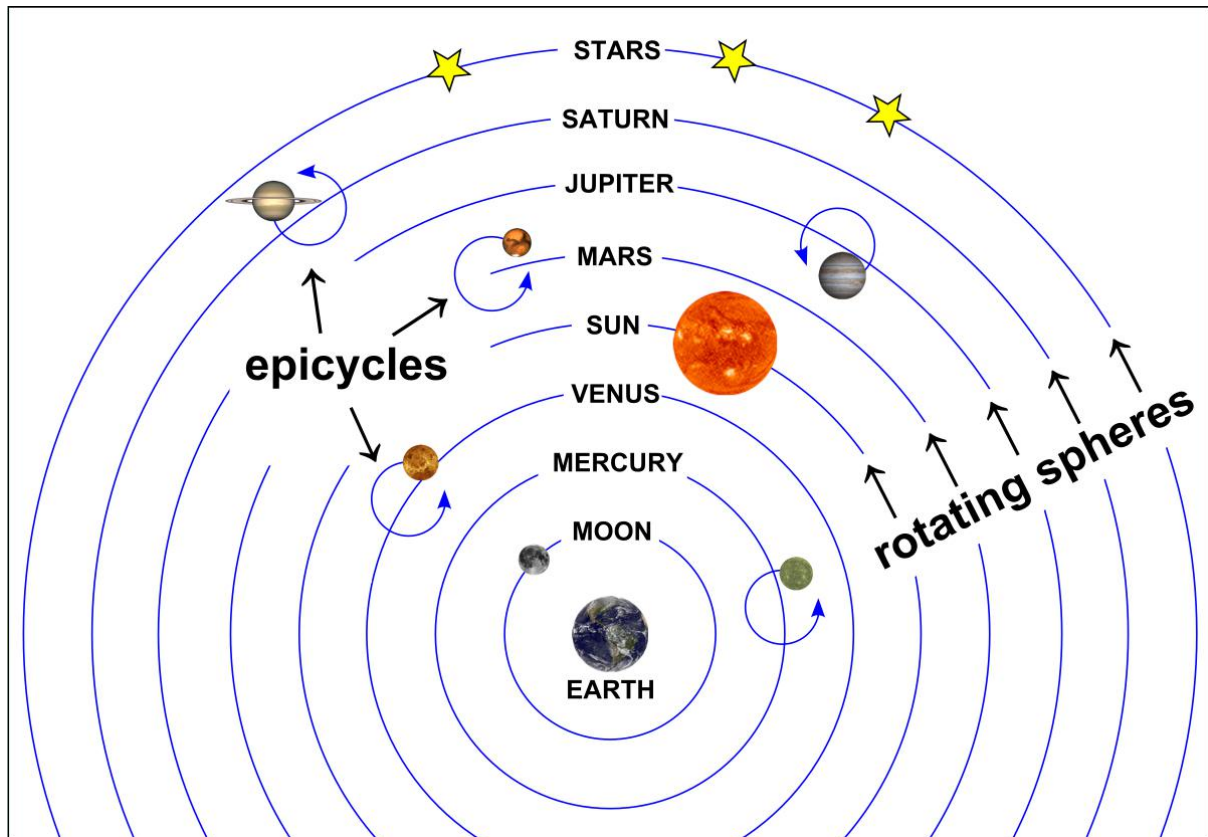


Figure 3. Hershey J., 2024. *Ptolemy's geocentric model of the universe* (not to scale). <https://www.faithfulscience.com/science-and-faith/brief-history-of-faithful-science.html> [visited at 02/09/2024].

- **Hero of Alexandria** demonstrated the combination of theoretical knowledge and practical engineering in his many inventions, such as the dioptra, a portable device based on gears, screws, and water levels used for both terrestrial and astronomical measurements. In his writings on mechanics and pneumatics, Hero of Alexandria described various breakthroughs, like automated machines and hydraulic systems, which were utilized in temples and theaters, demonstrating how scientific principles were applied in religious and entertainment contexts (Hero of Alexandria, *Pneumatics*, introduction). The work of Hero impacted future Islamic engineers like Al-Jazari, and Renaissance thinkers who aimed to revive ancient technologies.
- **Hypatia of Alexandria**, one of the last great thinkers of the ancient world, was instrumental in preserving and passing on Greek mathematical and astronomical knowledge in a period of decline. Her commentaries on Diophantus and Ptolemy played a crucial role in ensuring the survival of these works, which were later transmitted to the Islamic community and reintroduced to Europe during the Renaissance (Socrates Scholasticus, *Ecclesiastical History*, VII.15). Hypatia's tragic death symbolized the conclusion of the classical era and the start of a prolonged period of intellectual decline in the Western world, nevertheless her influence persisted through the works she preserved.

Figure 4 presents a thorough timeline that traces the key figures and their crucial contributions to the concepts of space and time from 600 B.C. to 600 A.D. This visual representation highlights the evolution of thought across different periods, illustrating how early ideas were refined and expanded over time, leading to a greater understanding of these fundamental concepts.

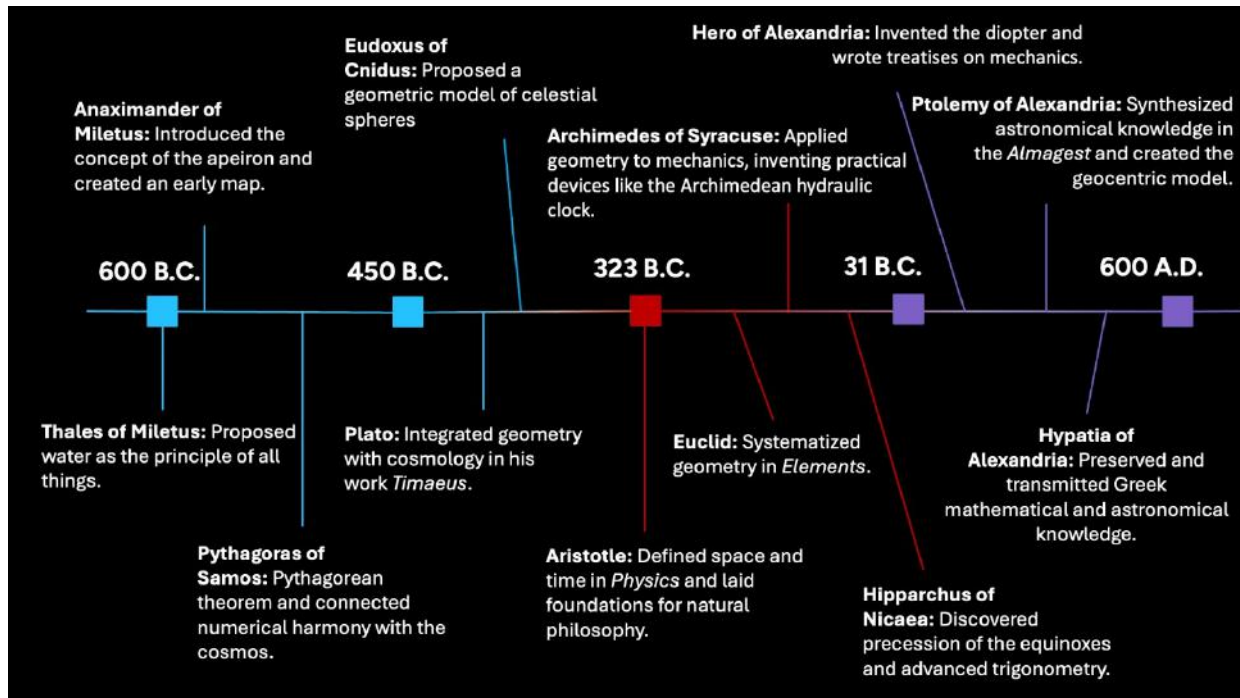


Figure 4. Timeline of Key Figures and Their Contributions to the Concepts of Space and Time in Ancient Greece (600 B.C. - 600 A.D.)

4.2 Geographical Analysis

This study utilized GIS mapping to locate various key hubs of scientific activity, representing the spatial patterns that supported the growth and spread of scientific concepts.

- Miletus and Samos:** These early centers were pivotal in the emergence of philosophical and scientific thought, promoting exploration that established the foundation for the growth of Western intellectual centers (Berggren, 2000). Due to its strategic geographical location, Miletus, a coastal city, prospered from trade and interactions with different cultures, leading to a diverse intellectual atmosphere.
- Athens:** The Academy and Lyceum were significant centers of learning during the Classical period, and the city became the intellectual capital of the Greek world. The city's rich cultural and educational environment fostered philosophical inquiry, resulting in substantial contributions to the comprehension of space and time (Faure, Valli, & Zucker, 2022). The vibrant exchange of ideas in Athenian society was further enhanced by its democratic nature, creating a conducive environment for the flourishing of scientific research.
- Alexandria:** Alexandria was a significant hub of knowledge and innovation during the Hellenistic and Roman periods, and it was home to the Library of Alexandria, which attracted scholars from all over the Mediterranean. This city became a nexus of education where ideas from Greek, Egyptian, Persian, and Indian cultures merged, leading to advancements in engineering, astronomy, and geometry (Jacob, 1996). Alexandria was an optimal center for the exchange of technological innovations and ideas due to its strategic location at the intersection of trade routes.
- Rome and Constantinople:** These cities played critical roles in the later periods, demonstrating the extension and perpetuation of Greek scientific centers. Rome, at the center of the Roman Empire, combined Greek science with Roman engineering and administrative skills, establishing a strong foundation for future scientific and technological development (Berggren, 2000). Constantinople, in its role as the new capital of the Roman Empire and later the Byzantine Empire, emerged as a hub for the preservation and transmission of Greek knowledge, especially through institutions like the Imperial Library.

These centers were not isolated but linked through networks of trade, conquest, and intellectual exchange, which resulted in the dissemination and adaptation of concepts throughout the ancient world. Figure 5 portrays these centers, emphasizing their tactical locations across the Mediterranean, which enabled ease of trade and cultural interaction.

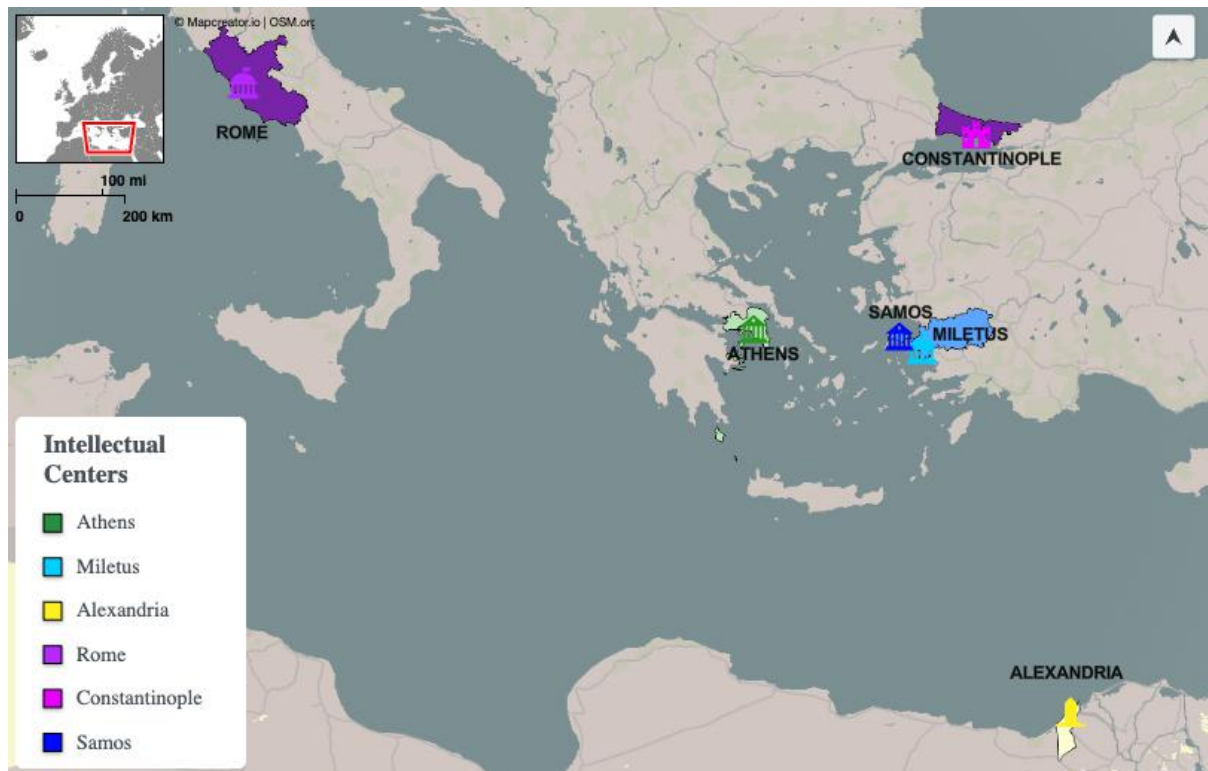


Figure 5. Map of Key Intellectual Centers in Ancient Greece (600 B.C. - 600 A.D.)

4.3 Temporal Patterns

The temporal analysis highlighted key tendencies in the evolution of scientific thought:

- **Pre-Socratic to Classical Transition:** This period witnessed a transition from mythological explanations to more rational and empirical approaches, which paved the way for systematic inquiries that characterized the Classical period (Sattler, 2020). This transition was initiated by philosophers such as Thales and Anaximander, who shifted toward naturalistic explanations for celestial phenomena.
- **Hellenistic Period:** This period was characterized by a significant increase in practical and mathematical advancements, with notable contributions to engineering, geometry, and astronomy. The creation of organizations such as the Library of Alexandria was important for promoting research and sharing information, which helped to foster interdisciplinary breakthroughs that greatly advanced scientific knowledge (Faure, Valli, & Zucker, 2022). During the Hellenistic era, scientific research became more professionalized, as scholars like Euclid and Archimedes developed methods that set the standard for their fields.
- **Roman and Early Byzantine Period:** This era centered on strengthening, safeguarding, and broadening existing knowledge, while also advancing in engineering and technology. During this period, scholars refined and expanded scientific theories and applications by building upon the foundations established by their predecessors (Hussey, 2002). The survival and influence of Greek scientific thought in Europe during the Renaissance were guaranteed by the adaptation of its content to new contexts during this time, particularly through the translation and transmission of texts to the Islamic nation.

Figure 6 depicts the trade routes between these intellectual centers, showing how the exchange of ideas facilitated the spread of scientific knowledge and technological innovations across different regions of ancient Greece. As shown in Figure 6, the trade networks connecting these hubs were instrumental in disseminating information throughout the ancient Greek civilization. The links among these central points provided an ongoing flow of scientific concepts, enhancing the diverse intellectual environment of that period.

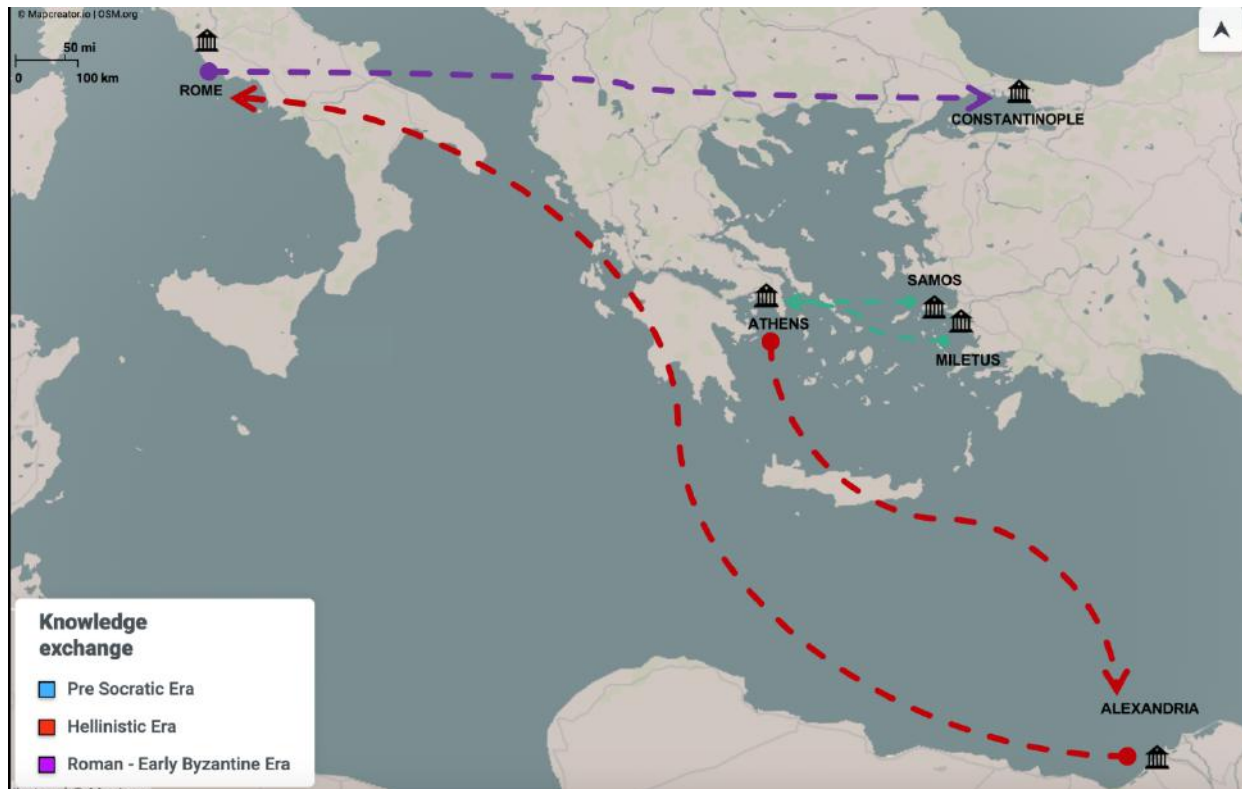


Figure 6. *Map of Trade Routes and Knowledge Exchange in Ancient Greece (600 B.C. - 600 A.D.)*

4.4 Influence of Socio-Cultural Factors

The analysis also underscored the importance of socio-cultural factors in shaping scientific activity:

- **Political Stability:** Periods of political stability, such as those following the death of Alexander the Great and the Athens democratic era, were associated with heightened scientific research and innovation. Jacob (1996) stated that a steady government created essential circumstances for academic activities, such as supporting research and building libraries and educational facilities. The support of rulers and wealthy citizens was also vital in backing scholars and advancing scientific expertise.
- **Educational Institutions:** The most notably educational institutions were the Academy, Lyceum, and Library of Alexandria, the establishment and support of which played a vital role in promoting scientific exploration and sharing of knowledge. These institutions established structured environments that enabled scholars to collaborate, debate, and expand upon one another's work (Hill, 2013).¹⁹ The significance of these institutions in the preservation and transmission of knowledge across generations is profound,

¹⁹ The establishment of formal schools of thought, such as the Pythagorean Brotherhood, solidified philosophical and scientific investigation, aiding in the advancement of a structured method for acquiring knowledge.

particularly in the context of the Western Roman Empire's collapse and the subsequent transfer of Greek knowledge to the Islamic world.

Interdisciplinary Interactions: The collaboration among various scientific disciplines and the merging of philosophical ideas with practical experimentation were significant in pushing progress forward. Cross-disciplinary exchanges allowed a more holistic approach to addressing issues and developing new ideas, leading to breakthroughs in various fields (Faure, Valli, & Zucker, 2022). The rapid progress of knowledge during this time was facilitated by the cooperative effort of Greek philosophers, mathematicians, and engineers who frequently collaborated in scientific investigations.

4.5 Key Contributions to Space and Time

The research identified several key contributions to the understanding of space and time:

- **Measurement Tools:** The developed instruments were sundials, water clocks, and astrolabes which facilitated more precise measurements of time and distances. In addition to enhancing daily life, these instruments enabled more precise scientific observations and experiments (Hussey, 2002). The practical use of theoretical knowledge is shown through the improvement of these tools, demonstrating the Greek value of precision and accuracy in scientific research. In particular, Anaximander's creation of the *gnomon* (Figure 2) demonstrates the ancient Greek attempt to accurately navigate and measure time (Hill, 2013). The *gnomon* (Figure 2), a basic but highly effective instrument, played a crucial role in identifying solstices and equinoxes, leading to a key advancement in Greek comprehension of temporal patterns and the rhythms of the natural world. The incorporation of this tool in Greek society, especially in religious and agricultural settings, shows an early connection between practical observation and the philosophical desire to measure and understand natural events, linking empirical methods with abstract ideas about time. Anaximander's advancements in these fields not only pushed Greek knowledge of time and space forward but also established the basic principles that would later be developed by future thinkers.
- **Maps and Cartography:** Improvements in cartography, such as developing detailed maps and geographic models, enhanced spatial comprehension. Precise maps were crucial for navigating, trading, and expanding empires, showing the practical uses of scientific understanding (Berggren, 2000). Anaximander is recognized for developing an early map of the known world, showing spatial connections, and suggesting a systematic understanding of the world (Hussey, 2002). His impact on Greek as well as afterward Roman practices can be observed in Ptolemy's complex maps. The advancements in cartography consisted of technical accomplishments and also reflected broader intellect regarding the world's nature and humanity's position in it.
- **Philosophical Theories:** Philosophers' theoretical investigations laid the groundwork for coming scientific advancements. Philosophers such as Plato and Aristotle's contributions provided a basis for future scientific inquiry, constructing the way following generations approached the study of the natural world (Sattler, 2020). The philosophical concepts about space, time, and motion had a lasting impact on the development of science, influencing both medieval scholars and Renaissance thinkers.

The ancient Greeks were pioneers in the integration of empirical observation with theoretical models, which resulted in substantial technological advancements. These innovations not only addressed practical needs but also enhanced the Greek awareness of space and time. The following table summarizes some of these key technological developments and their impact:

Table 2. Summary of Key Technological Innovations in Ancient Greece

Innovation	Inventor/Philosopher	Date	Description	Significance
<i>Gnomon</i>	Anaximander	c. 6th Century B.C.	A simple device that casts a shadow, used to determine the solstices and time of day.	Pioneered the concept of measuring time and understanding celestial movements.
Anaximander's map	Anaximander	c. 6th Century B.C.	One of the earliest known maps of the world, depicting the known lands surrounded by oceans.	Provided a foundational understanding of geography and the concept of mapping the Earth.
Archimedes' Hydraulic Clock	Archimedes	c. 3rd Century B.C.	A water-powered clock that used a consistent flow of water to measure time.	Important for its innovative approach to timekeeping, representing the application of hydraulic principles to practical use.
Antikythera Mechanism	Unknown (Greek)	c. 100 B.C.	An ancient analog computer used to predict astronomical positions and eclipses.	Demonstrates advanced understanding of astronomy and mechanical engineering in ancient Greece.
Hero's Dioptra	Hero of Alexandria	c. 1st Century A.D.	An early surveying instrument used for measuring angles and determining the alignment of structures.	Played a crucial role in the development of surveying and engineering, influencing the design and construction of buildings.
Ptolemaic Geocentric Model	Ptolemy	c. 2nd Century A.D.	A model of the universe that placed Earth at the center, with planets and stars revolving around it.	Dominated Western astronomical thought for over a millennium, influencing the development of astronomy.

As shown in Table 2, these innovations were instrumental in shaping Greek scientific thought. The *gnomon* (Figure 2), for instance, provided early perspective into time measurement, while the Antikythera Mechanism (Figure 1) represented a sophisticated understanding of celestial cycles. These advancements serve as a foundation for future scientific progress by demonstrating the Greek commitment to exploring and quantifying the natural world.

4.6 Conclusion of the Results

The examination of how ancient Greek scientists perceived space and time highlights the influence of geography, intellectual exploration, and socio-political factors on the evolution of scientific ideas from 600 B.C. to 600 A.D. Important figures like Thales, Pythagoras, Aristotle, and Ptolemy were not isolated achievements but rather the outcome of accumulated knowledge nurtured in dynamic intellectual centers like Miletus, Athens, and Alexandria. These educational hubs, maintained by stable political climates and innovative academic institutions, fostered the exchange of ideas across various fields, resulting in significant progress in comprehending space, time, and the physical world.

This study emphasizes the interconnectedness of ancient Greek scientific progress and its impact on subsequent generations by placing these scientific accomplishments within their broader temporal and geographical contexts. The research shows the importance of socio-cultural aspects such as political stability, for fostering a conducive atmosphere for scientific advancement. Understanding these dynamics gives us important insights into the factors that promote scientific exploration and technological progress, whether in ancient times or the present day.

5 Discussion

This section examines the profound impact of these early Greek thinkers, drawing connections between their work and the broader socio-cultural and geographical contexts that facilitated their achievements. It also contemplates the implications of these findings for our understanding of the history of science and its ongoing relevance.

5.1 Interpretation of Key Findings

The results of this study focus on the important influence that geographical and socio-political factors had on the formation of scientific ideas in ancient Greece. The concentration of intellectual activity occurred in specific centers, namely Miletus, Athens, Alexandria, and Rome. These locations were favorable for intellectual research due to the combination of multicultural, economic, and political elements. The emergence of these ideas in prominent academic centers underscores the value of these institutions in cultivating a climate of curiosity that was crucial to the progress of scientific thinking.

The case of Pythagoras further demonstrates how the Greeks combined philosophy and mathematics. His conviction that numerical harmony is a key element of the cosmos set the foundation for the advancement of mathematical astronomy, which would become essential for later astronomers such as Hipparchus and Ptolemy. This proto-scientific approach not only offered a structure for interpreting the universe but also indicated a broader Greek worldview that aimed for order and harmony in both natural and abstract realms (Iamblichus, *Life of Pythagoras*, 29).²⁰ The endurance of Pythagorean concepts during the Renaissance and beyond reveals the fundamental importance of these contributions to Western philosophy.

Moreover, the findings also exhibit the role of practical tools and technologies in shaping the understanding of space and time. Anaximander's *gnomon* (Figure 2), for instance, was not merely a time-measuring instrument but a symbol of the Greek effort to quantify and systematize the natural world. This innovation, alongside others such as the Antikythera Mechanism (Figure 1), expresses the ancient Greek focus on accuracy in studying the universe, a focus that would continue to effect scientific research for centuries (Freeth et al., 2006).

²⁰ Iamblichus. *Life of Pythagoras*. 29. Iamblichus elaborates on the Pythagorean belief in the cosmic significance of numbers, showing how it impacted both mathematical theory and Pythagorean cosmology.

5.2 Comparison with Existing Literature

The research results are consistent with and build on previous literature that emphasizes the importance of intellectual hubs and socio-political steadiness in promoting scientific creativity. Scholars such as Sattler (2020) and Berggren (2000) have pointed out the importance of cities like Athens and Alexandria in the advancement of scientific ideas, because of their lively cultural and educational atmospheres. Nevertheless, this research provides fresh perspectives through the utilization of GIS mapping to visually represent the diffusion of ideas, offering a more intricate perception of how these ideas were distributed and connected among different areas. This method adds to traditional historical studies and spotlights the relevance of geographic settings in intellectual history (Berggren, 2000).²¹

This study emphasizes the collective character of scientific progress in ancient Greece, in contrast to the prevalent attention to the contributions of individual thinkers in the existing literature. The association of scholarly activities across various cities implies that advancements were not the outcome of solitary ingenuity, but rather the result of collaborative efforts within supportive environments. This perspective opposes the "great man" theory of history and underlines the meaning of intellectual networks in the advancement of scientific concepts (Jacob, 1996).

Furthermore, the study's emphasis on the interdisciplinary aspects of Greek scientific thinking aligns with current academic work investigating the blending of different areas of study in the ancient world. Cuomo's (2007) research on the connection between technology and philosophy in ancient Greece agrees with this study's discoveries on the real-world uses of scientific knowledge, like the creation of time-keeping tools and mechanical innovations (Cuomo, 2007). By highlighting these interdisciplinary interactions, the study contributes to a growing body of literature that seeks to grasp the holistic nature of ancient scientific inquiry.

5.3 Implications of the Study

The implications of this study extend beyond the historical context of ancient Greece; they also provide valuable insights for contemporary scientific practice. A major implication is the value of establishing and maintaining intellectual hubs where ideas can be freely exchanged and developed. The importance of cities like Athens and Alexandria in promoting scientific innovation stresses the necessity for modern societies to support educational institutions and research centers as hubs for cultivating new ideas (Fraser, 1972).²²

The role of interdisciplinary collaboration is another crucial implication for advancing scientific progress. The Greek case shows that major progress frequently happens when different areas of study intersect. In the modern interconnected world, it is essential to promote interdisciplinary research to tackle the diverse challenges we encounter. The integration of philosophy, mathematics, and empirical observation in ancient Greece can serve as a model for existing efforts to bridge the gaps between the sciences and the humanities (Faure, Valli, & Zucker, 2022).

The research also showcases how crucial socio-political balance is for promoting scientific investigation. The stability during the reigns of leaders such as Alexander the Great allowed for the development of intellectual pursuits, such as the funding and construction of libraries and educational institutions (Plutarch, *Life of Alexander*, 7.8). This discovery indicates that it is substantial for current policymakers to focus on forming stable conditions that foster scientific

²¹ Berggren, J. L., 2000. *Episodes in the Mathematics of Medieval Islam*: Springer Science & Business Media. Berggren discusses the centrality of Miletus as an early hub of scientific thought and its influence on the mathematical and astronomical developments of the time.

²² Fraser, P. M., 1972. *Ptolemaic Alexandria*: Clarendon Press. Fraser offers a detailed examination of the Library of Alexandria as a key institution for the preservation and dissemination of scientific knowledge during the Hellenistic period.

and intellectual progress, recognizing that political and economic solidity are closely linked to the evolution of knowledge.

5.4 Limitations of the Study

Although this study has made valuable contributions, it also has certain limitations. A major drawback is the dependence on secondary sources, which could lead to bias or an incomplete understanding of the historical background. Even though GIS mapping offers important information on where scientific activity is located geographically, its effectiveness is constrained by the quality and quantity of historical data available. The importance of being careful in drawing firm conclusions from analyzing ancient maps and data using modern methods presents a noteworthy challenge (Sorabji, 1988).²³

Another restriction is the concentration on a specific group of well-known individuals and educational hubs. While focusing on key contributors to Greek scientific thought, this method might ignore the contributions of less renowned characters and areas. Future research could address this gap by exploring the roles of other thinkers, including women and non-Greek scholars, in the development of ancient science and philosophy.

Additionally, focusing on where intellectual activity is located in the study may hide the intricacies of cultural exchange and the spread of ideas between various regions. Although the study illuminates the substance of intellectual centers, it does not comprehensively investigate how ideas were transferred among these hubs and other regions in the ancient world. Further research could examine these networks of exchange in greater detail, leading to a more thorough grasp of the worldwide influence of Greek scientific ideas (Diller, 1938).²⁴

5.5 Suggestions for Future Research

Future research could broaden the geographical scope to encompass other regions of the ancient world, such as the Near East and North Africa, to investigate the impact of cross-cultural exchanges on the progress of scientific thought in these territories, based on the insights obtained from this study. This broader perspective could provide valuable understandings into the ways in which Greek scientific ideas were adapted and transformed in different cultural and political contexts (Nutton, 2013).²⁵

The transmission of Greek scientific knowledge to subsequent cultures, particularly during the Byzantine and Islamic periods, could also be the subject of additional research. Understanding how these ideas were preserved, adapted, and expanded upon by later scholars, could offer an enhanced view of the global legacy of Greek science (Fraser, 1972).²⁶

Finally, future studies could explore the contribution of women and marginalized communities to the growth of Greek science and philosophy. Though the primary focus of this research has been on well-known male individuals, there is proof that women also had considerable roles in

²³ Sorabji, R., 1988. *Matter, Space and Motion: Theories in Antiquity and Their Sequel*: Duckworth. Sorabji critically assesses the limitations of ancient scientific theories, particularly in their attempts to explain the nature of matter and motion, and discusses the challenges of interpreting these theories within contemporary contexts.

²⁴ Diller, A., 1938. *Studies in Greek Manuscript Tradition*: Princeton University Press. Diller examines how cultural exchanges impacted the preservation and interpretation of Greek scientific knowledge through manuscript traditions.

²⁵ Nutton, V., 2013. *Ancient Medicine*: Routledge. Nutton examines the role of interactions between Greece and neighboring areas like Egypt and Mesopotamia in advancing medical knowledge, emphasizing the wider influence of Greek scientific ideas.

²⁶ Fraser, P. M., 1972. *Ptolemaic Alexandria*: Clarendon Press. Fraser discusses the role of Alexandria as a channel for the transmission of Greek scientific knowledge to later cultures, specifically in the Byzantine and Islamic eras, guaranteeing the ongoing presence of this intellectual legacy.

the intellectual sphere of ancient Greece. Examining their contributions could provide a more inclusive and nuanced understanding of the history of science (Rihll, 1999).²⁷

6 Conclusion

The objective of this research was to investigate the impact of ancient Greek scientists and philosophers to the understanding of space and time, focusing on the period from 600 B.C. to 600 A.D. Through a geographical approach grounded in biographical analysis, the study aimed to reveal the influence of particular regions, centers of intellectual activity, and socio-political environments on the evolution and spread of scientific ideas in ancient Greece. The main focus of the research was on how these factors influenced the way Greeks understood space and time and how they continue to influence Western intellectual traditions.

The study showed that scientific activity in ancient Greece was mainly centered in key intellectual hubs like Miletus, Athens, and Alexandria in terms of the distribution of space and time concepts. These cities were crucial in creating a setting that supported intellectual exploration, allowing thinkers such as Anaximander, Pythagoras, Aristotle, and Ptolemy to cultivate and improve their ideas. Anaximander brought forth the concept of the infinite, Pythagoras focused on mathematical balance, Aristotle approached space and time systematically, and Ptolemy proposed a geocentric model (Figure 3), all stemming from the rich intellectual environment of the time.

Moreover, the research emphasized the significance of cross-disciplinary collaborations, combining philosophical theories, practical observations, and technological developments to make notable progress. The Greeks demonstrated their ability to combine theory with practice by creating practical tools like the *gnomon* (Figure 2) and the Antikythera Mechanism (Figure 1), which resulted in more accurate scientific observations and a greater knowledge of the universe.

The geographical perspective also showed how important socio-political stability and educational institutions are for advancing scientific development. During times of peace, like in the Classical Period, there was a rise in scientific activity due to the creation of organizations such as the Aristotle's Lyceum, which played a key role in gathering and sharing Greek scientific knowledge.

Although the research offers valuable insights, it is not without its limitations. Relying on secondary sources can lead to biased information and may create an incomplete picture of the historical background. Furthermore, the focus on famous individuals and intellectual hubs could result in the neglect of the ideas from lesser-known scholars and areas. The innovative geographical approach poses challenges for historical data accuracy and completeness.

Building on the findings of this study, future research could expand the geographical scope to include other regions of the ancient world, such as the Near East and North Africa, to explore how cross-cultural exchanges influenced the evolution of scientific ideas. Additional studies could also explore how Greek scientific knowledge was passed on to later societies, especially during the Byzantine and Islamic eras. A supplementary prospective area for future study is the examination of the contributions of women and marginalized groups to Greek science and philosophy.

In summary, this research has thoroughly analyzed how ancient Greek scientists and philosophers perceived and comprehended space and time. By placing these findings in their wider historical and geographical settings, the study highlights the interconnectedness of Greek scientific advancements and their lasting impact on future periods. The results underscore how crucial it is to have collaborative research, institutional support, and cross-cultural exchanges to promote scientific innovation, offering valuable lessons that remain relevant in the modern era.

²⁷ Rihll, T. E., 1999. *Greek Science in Context*: Ashgate. Rihll advocates the frequently disregarded roles of women and marginalized communities in Greek science, pushing for a historical narrative that acknowledges their importance in the advancement of scientific knowledge.

The enduring impact of these ancient thinkers continues to influence how we see the world, emphasizing the timeless nature of their contributions to the history of science.

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ΑΙΓΙΔΑ



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ΧΟΡΗΓΟΙ



ΥΠΟΣΤΗΡΙΞΗ



ΜΕΓΑΡΟ
ΜΟΥΣΙΚΗΣ
ΑΘΗΝΩΝ