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EARLY MARITIME NAVIGATION - TEACHER BACKGROUND INFORMATION

From Magic Needle to Sophisticated Instrument: The Magnetic Compass

China may have been the first, but it failed to advance the needle's potential.
The lodestone, whose technical name is magnetite, is a naturally occurring mineral with magnetic properties. Knowledge of "lodestone's" ability to attract iron was known in ancient Greece. The ability of this rock to point in a preferred direction when suspended was, however, first discovered by the Chinese. A small iron needle when rubbed against a piece of loadstone will point to specific direction when floated in water. In China, this pointing ability of magnetic material was framed in the mystical terms of Feng Shui. In this mystical system, spiritually significant buildings and even every day structures had to be oriented in space in such a way as to put them in harmony with the universe. The special pointing ability of the loadstone provided the correct directions. The early history of how and where this mystical pointing ability of magnetic material came to be harnessed as an instrument of marine navigation remains fuzzy. The first in the process occurred when people observed that a magnetized needle seemed to point to a specific geographic direction - North. Again the Chinese may have first noticed this.

> "Magicians rub the point of a needle with lodestone; then it is able to point to the south. But it always inclines slightly to the east, and does not point directly south. It may be made to float on the surface of water, but it is then rather unsteady… It is best to suspend it by a single cocoon fibre of new silk attached to the center of the needle by a piece of wax. Then, hanging in a windlass place, it will always point to the south."
>
> Shen Kua, Meng Ch'I Pi T'an, 1088 C.E

References to a pointing needle appear in Europe from the 1180s C.E.

Alexander Neckam (1157-1217), an English monk, had studied and lectured at the University of Paris in the 1180s C.E. In his work *De Naturis Rerum*, which was widely circulated by the end of the 12thc century, describes what he saw, probably when crossing the English Channel sometime in the 1180s C.E.:

> "The sailors, moreover, as they sail over the sea, when in cloudy weather they can no longer profit by the light of the sun, or when the world is wrapped it in the darkness of shades of night, and they are ignorant to what point of the compass their ship's course is directed, they touch the magnet with a needle. This then whirls round in a circle until, when its motion ceases, the point looks direct to the north."

This image of a ship's captain bending over iron needle floating on water and then imbuing mysterious power to the iron needle by spinning around by the action of magnet, suggests the captain's sorcerer like power of navigation . One can only imagine the great impression that it made on those who observed it.

In his other work, De Utensibilus, Neckam writes,

> "They also have a needle placed upon a dart, and it is turned and whirled around until the point of the needle looks north-east [sic for North, but maybe he unintentionally observed variation]. And so sailors know which to steer when Cynosura is hidden by the clouds." [Cynosura is the Medieval name for the constellation Ursa Minor (Little Bear) in which Polaris the North Star resides.]

Then there is Guyot de Provins's lovely poem written around the 1180s or 1190s C.E. He was a monk in Clervaux and Cluny and travelled a lot. This poem gives a very precise description of magnetic needles navigational utility.

"This same (the pole-) star does not move, and
They (the mariners) have an art which cannot deceive,
By the virtue of the magnet,
An ugly brownish stone,
To which Iron adheres of its own accord.
Then they look for the right point,
And when they have touched a needle (on it)
And fixed it on a bit of straw,
Lengthwise in the middle, without more,
And the straw keep it above;
Then the point turns just
Against the star undoubtedly.
When the night is dark and gloomy,
That you can see neither star nor moon,
Then they bring a light to the needle;
Can they not then assure themselves
Of the situation of the star towards the point? (of the needle)
By this the mariner is enabled
To keep the proper course;
This is an art which cannot deceive."

We have no knowledge of where in Europe these two authors observed the needle. Neckam may have observed it in Italy, where he had once accompanied the Bishop of Worcester. Guyot did travel to the Near East during the Third Crusade (1189 – 1192). Did he experience it on an Italian ship or from an Arab source? The latter seems less probable since the earliest sighting of the needle in Arab literature is found in The Book of Merchant's Treasure, where the author Baylak al-Kibjaki, recalls seeing in 1242. The Medieval historian Lynn White points out that the first mention of the needle in a Persian story of 1232-3.

The conventional story contends that knowledge of this pointing magnetic needle came to Europe in the latter half of the 13th century from China via the Arabs, who had long handled all the maritime trade with China and the West. To date, there is not enough historical evidence to prove or disprove this view. When and how the magic magnetic needle first made its way to Europe may never be known.

The important story is not that it was first observed in China, but rather that the states of Western Europe quickly linked this wondrous needle to their ambitions to command the sea and hence trade. As a result, the conversion of this floating needle into a practical navigational instrument became a far more intense scientific and technological effort in Western Europe than it did in China or even in the Islamic world. First there were the engineering challenges of designing an ever more precise instrument that could work reliably in the harsh environment of a ship. Making the magnetic compass into an effective marine navigational tool also spurred the development of science, mathematics, and cartography. The first step was to create a science to explain why the needle behaved the way it did.

The question as to why China did not pursue the compass as Western Europe did will be taken up in later in the module.

Why was Western Europe more receptive to the potential of the magnetic compass?

The story of the widespread development and diffusion of the magnetic compass technology in Western Europe maritime practice originates from the economic and geopolitical importance and geographic realities of the Mediterranean Sea. From the Bronze Age until the Fall of Rome, nowhere in the world was the volume and diversity of maritime trade and culture greater than in the Mediterranean Sea. Though the geography of water created an extensive trade network that reached all the way to India and down the coast of East Africa, there were long-standing seasonal prohibitions as to when goods could move through the Mediterranean.

In *Works and Days*, ancient Greek poet Hesiod, who lived somewhere between 750 B.C.E. and 650 B.C.E., advised that "The 50 days after the summer solstice … is the right time for men to sail the seas." During classical Greece, the Mediterranean was closed to maritime trade for nearly half the year. This prohibition continued unabated under Roman rule. In 390 C.E., Flavius Vegetius Renatus wrote *De re militari, or Epitoma rei militaris*, a military treatise on the training, organization, tactics, and strategy of the Roman army. It is clear in his rules for using the Mediterranean to meet the logistical needs of the army, that he is well aware of the sea's seasonality:

> "From the 6th day before kalends of June until the rising of Arcturus, that is until the 18th before the kalends of October, is believed to be the safe period of navigation … From then up to the 3rd before the ides of November, navigation is uncertain. … From the 3rd before the ides of November to the 6th before the ides of March, the seas are closed."

Vegetius words represented the broader Roman Law of the period. In 380 C.E. Emperor Theodosius I ordered that maritime trade in government cargoes will only take place from 1 April to early October.

> "From the month of November, navigation shall be discontinued; the month of April since it is just before the summer, shall be employed for the acceptance of cargo. The necessity of such acceptance from the kalends of April to the kalends of October shall be preserved permanently; but navigation shall be extended to the day of ides of aforesaid months"

Why would profitable trade be suspended for nearly half-a-year? Why was the Mediterranean closed during these months? Vegetius provides us with the answer "scant daylight, long nights, dense cloud cover, poor visibility, and the violence of winds doubled by the addition of rain" made sailing quite dangerous. One can infer from Vegetius statement that he placed reduced visibility over storms as the principal danger. Reduced visibility nullified the use of the pole star and the sun as navigational tools once out of the sight of land. In other words, contemporary navigational know-how could not overcome the risks posed by the meteorological conditions that prevailed for half the year. Roman dictate of Mare Clausum continued well into the Medieval period.

The magical floating needle changed everything. As Neckam and Guyot de Provins observed, here was a device that could point the way even when all the known visible aids of navigation were hidden by clouds and darkness. By the late Middle Ages, maritime trade networks were expanding in scope and scale, so there was a real pent up demand for a solution to Mare Clausum. Of course, considerable innovation would be needed to move from a crude needle to practical and accurate device for navigation. By the start of the 14th century, the marine compass as we know it today appeared on Italian trading ships. It consisted of a disc turning freely on a pivot. The magnetized needle was attached below the card. On top, the disc was divided into a number of directions. The economic impact of the magnetic compass was dramatic. Maritime trade became an all-year activity. Shipping records show the Italian City states doubling the volume of their trade.

The magnetic compass's development continued as each of the Atlantic facing nations (Portugal, Spain, England and the Dutch Republic) in turn looked to the oceans for a trade advantage. Looking for a way to break the trade monopoly that Italian City states and the Arabs had with the East, Portugal sought a strategic advantage in the connectivity of the world's oceans. Portugal managed to create its own trade monopoly over the Eastward ocean route to Asia, i.e. down around Africa and then Eastward along the Indian Ocean. Feeling blocked by Portugal's sphere of influence, Spain became receptive to Columbus's offer to find a westward route across the Atlantic Ocean to the riches of the East. In 1493, Ferdinand and Isabella of Spain pursued papal support for their claims to the New World, hoping to bar Portugal and other countries from as much of the Western Hemisphere as possible. Spanish and Portuguese ambassadors accepted the Treaty of Tordesillas (1494). The line of demarcation was set at 370 leagues (1,185 miles) west of the Cape Verde Islands, or about 46°30′ W of Greenwich. Portugal was awarded territory east of the line, which was somewhere in the Atlantic Ocean, and Spain acquired the territory west of the treaty line. A peaceful solution was reached between the two Roman Catholic countries. However, the issue was far from settled because the Dutch Republic and England joined the competition for trade routes to the East and voyages of exploration to the New World. In the quest to exploit the connectivity of the world's ocean, magnetic compass proved an invaluable navigational instrument.

Does the Compass Really Point to the North?

It was initially believed that the magnetic needle pointed to geographic north because it was attracted by some special force to the North Star itself. However, as use of the compass became more widespread, it became apparent that the compass did not point to geographic North. In the Mediterranean, this error was small and compass makers found ways to correct for it. But as European maritime ambitions turned to the North Atlantic, this error became significant. Columbus first observed, during his Atlantic Ocean voyages, that the difference between geographic North and where the compass pointed could be large. Even more puzzling, was the observation that this compass error changed dramatically as one crossed the Atlantic, particularly in the northern latitudes. It must have been a frightening thought for a ship's captain to discover that his compass course was not pointing him in the correct direction. It was certainly a serious problem for the English and Dutch who, for geopolitical reasons, were desperately seeking northeast and northwest passages to the Spice Islands and the wealth of China. If the magnetic compass was ever to advance a society's global ambitions, then one had to understand the how and the why of compass behavior.

In the closing years of the 16th century, William Gilbert (1544 – 1603) developed a new branch of science to better understand the compass. In 1600, he published De Magnet the world's first scientific treatment of magnetic phenomena and geomagnetism. Gilbert criticized earlier and unscientific explanations of the compass.

> "For this reason the crowd of philosophizers, in order to discover the reasons of the magnetical motions, called up causes lying remote and far away. And one man seems to me beyond all others worthy of censure, Martin Cortes, who, since there was no cause which could satisfy him in the whole of nature, dreamed that there was a point of magnetical attraction beyond the heavens, which attracted iron. Peter Peregrinus thinks that the direction arises from the poles of the sky. Cardan thought that the turning of iron was caused by a star in the tail of the Great Bear; Bessard, the Frenchman, opines that a magnetick turns toward the pole of the zodiack. Marsilius Ficinus will have it that the loadstone follows its own Arctick pole; but that iron follows the loadstone, straws amber; whilst this perhaps follows the Antarctick pole—a most foolish dream. Others have recourse to I know not what magnetick rocks and mountains. Thus it is always customary with mortals, that they despise things near home, whilst foreign and distant things are dear and prized. But we study the earth itself and observe in it the cause of so great an effect. The earth, as the common mother, has these causes inclosed in her innermost parts …"

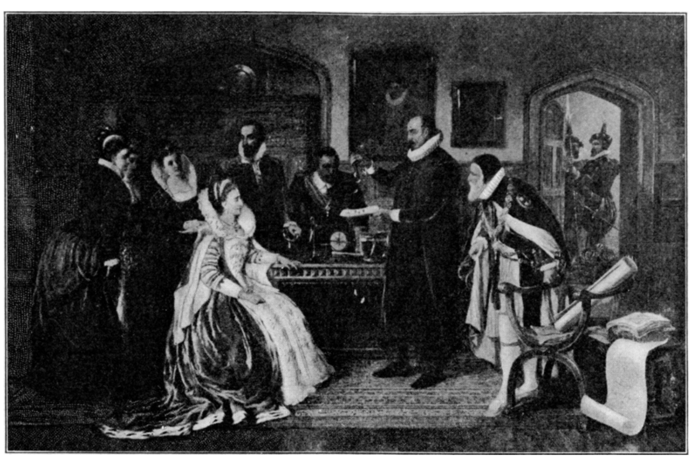
Gilbert called the difference between North on the compass and geographic north “variation.” Listing all the farfetched explanations that have clouded people’s understanding of variation, he then argued that the answer lay in developing a new science to explain the behavior of loadstone and the magnetic needle.

Edward Wright (1561 – 1615) was one of England’s most prominent mathematicians, a lecturer on navigation to the English East India Company, and the man who developed the theory for the first useful map for ocean navigation.

In his introduction to Gilbert’s *De Magnet*, Wright underscores the importance of the magnetic compass to England’s maritime ambitions.

> “Nor truly in my judgment could you have chosen any topick either more noble or more useful to the human race, upon which to exercise the strength of your philosophic intellect; since indeed it has been brought about by the divine agency of this stone, that continents of such vast circuit, such an infinite number of lands, islands, peoples, and tribes, which have remained unknown for so many ages, have now only a short time ago, almost within our own memory, been quite easily discovered and quite frequently explored, and that the circuit of the whole terrestrial globe also has been more than once circumnavigated by our own countrymen, Drake and Cavendish; a fact which I wish to mention to the lasting memory of these men. For by the pointing of the iron touched by a loadstone, the points of South, North, East, and West, and the other quarters of the world are made known to navigators even under an overcast sky and in the darkest night; so that thus they always very easily understand to which point of the world they ought to direct their ship's course; which before the discovery of this wonderful virtue of the magnetick [needle] was clearly impossible.”

Gilbert’s work opened the door to the value of mapping the magnetic variation over the entire Earth. With such a map, one could then make the magnetic compass an effective navigational tool anywhere on the planet. By the end of the 17th century, England was the first nation to fund a survey of the Atlantic Ocean to map the magnetic variation.

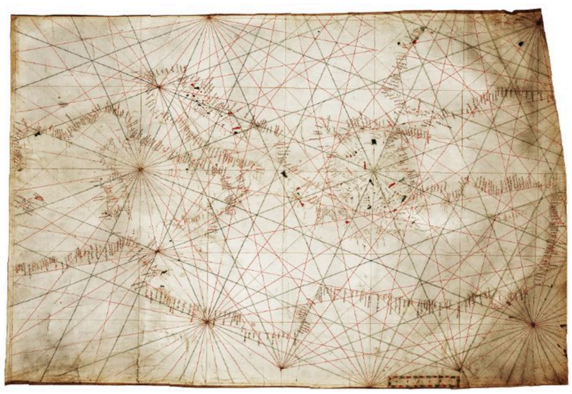


Importance of scientific study of magnetism to the State. William Gilbert explaining his work to Queen Elizabeth I

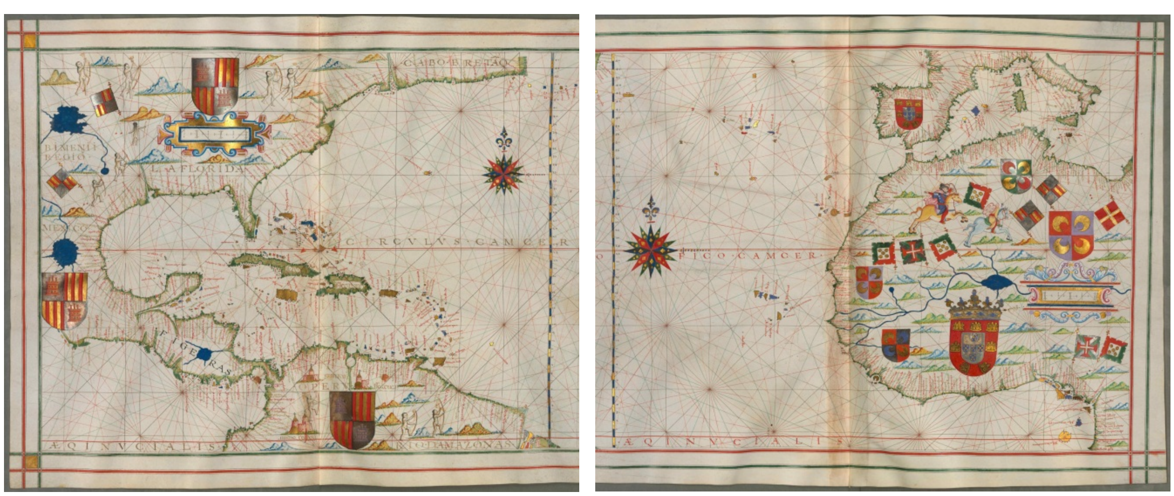
__Visualizing Moving over the Sea: The Emergence Portolans__

The emergence of better tools for visualization space accompanied the development of the magnetic compass. The increased trade made possible by the compass, also created a demand for more accurate ways to portray the spatial relationships between ports. The first accurate maps seen in the in the Middle Ages, called portolans, arose from the need of maritime navigation. With the aid of compass, portolans allowed ship captains to visualize and plan their routes across the Mediterranean. The design of a portolan reveals that its utility depended on the magnetic compass. The portolans is full of "compass roses" to help plan the sailing route between two points. The two technologies co-evolved. Improvements in one led to improvements in the other.

Below is a portolans from 1350. Notice the many compass directions printed on it.



As portolans came into wider use, cartographers increased their sophistication by including some measure of distance, particularly latitude and even some indication of longitude. Looking at the 16th century Portuguese portolans below, one can see the emergence of a more complicated grid structure. Latitude is measured in units along a vertical line. This vertical line, may be the Portuguese cartographer's intent to depict the longitude line established by the Treaty of Tordesillas.



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To Command the Trade, One Needs to Understand the Sphere

Although it represented a dramatic improvement in cartography, all these portolans had a fundamental flaw. They could not give you the course to steer between as one sailed to very distant points. As one can imagine, this creates a problem for any nation that wants to "command the trade" over vast oceans. The problem lay in the fact that longitude and latitude are coordinates drawn on a sphere. Although navigators knew that the Earth was a sphere, they had no idea about the mathematics needed to relate the coordinates on a sphere to the coordinates on a flat piece of paper. Carrying globes on their ships proves costly and impractical. Flat paper was the next technology.

However, there is no way to represent all the spatial information on the spherical Earth on a flat piece of paper. Some of the spherical information can be accurately depicted, but then the rest of the information must be distorted. The challenge for 16th century cartographers and mathematicians was to decide on the subset of information essential for ocean navigation. They concluded the directions between places were absolutely essential. A navigation chart should answer the question, "where do I to point my ship" in order to get from one location to another, e.g. from Bermuda to London. To answer this question, the navigator drew a line between the two locations and then measured the compass angle. The solution was the famous Mercator map, or more correctly the Mercator-Wright map. If one looks at it very carefully, one can see that distances on the map are increasingly distorted at higher latitudes. It took considerable mathematical ingenuity to prove that the Mercator-Wright map worked.

Mercator-Wright Map, 1599

Accurate Measure of Time Essential for Ocean Navigation

To master ocean navigation, one must be able to plot a direction, and measure both latitude and longitude. By the 16th century, navigators were confidently measuring the first two. By the end of the 16th century, they also had the technology to plot courses on a map. The measurement longitude, however, remained elusive until the end of the 18th century. Everyone knew that the answer was a clock. But everyone was also convinced that designing an accurate mechanical clock that would work on a ship was impossible. Thanks to the support of the British Admiralty, who saw the solution of the longitude problem as essential to its sea power, John Harrison, a brilliant craftsman, did the impossible. The development of the Harrison clock is a remarkable story unflinching perseverance and brilliant problem solving. It is also a story of a humble clockmaker facing the obstacles of England's class structure.

It must be emphasized that it is the fierce competition among the Western European states to command the sea that sustained the progress in marine navigation. This multipolar geopolitical rivalry among similarly sized states produced a lot of conflict and war, but it also produced an open creative environment receptive to new scientific and technological approaches to marine navigation. Perhaps the absence of such a competitive environment within the both the Islamic empire and the Chinese empire, may explain in part why Western Europe leapt ahead of the rest the world in its ambitions to command global trade and the sea.

The Flow of Ideas