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Multifaceted Mathematicians

Juan M. Sepulcre
University of Alicante

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Juan Matías Sepulcre

Department of Mathematics, University of Alicante, Alicante, SPAIN
JM.Sepulcre@ua.es

Synopsis

This report attempts to provide an overview of some of the mathematicians who have combined their mathematical knowledge with other academic and non-academic specialities. The various examples given, many of them included in the well-known MacTutor History of Mathematics archive, corroborate the fact that although the idea of the typical polymath has receded with the passage of time, until the end of the Renaissance, most well-known mathematicians were also well-versed in a number of different sciences such as philosophy, astronomy, and physics. We also highlight other, less common combinations of knowledge, in famous mathematicians who were experts in other disciplines or activities of a totally disparate nature.

Throughout history, mathematics has been used in activities concerned with the immediate environment and material reality of its practitioners. In fact, we can say that this science is basically an exploration of the various complex structures of the universe. Exact sciences constitute the basis for any kind of scientific and technological development and many disciplines make use of mathematical models to resolve their problems. Furthermore, mathematics has been used as an instrument in the creation of artistic or architectural elements of great beauty and also in the field of entertainment.

It is important to recall that specialising in different scientific fields was not the purpose of the original medieval universities; these were characterised by universal studies. In fact, the separation of arts and sciences did not come about until the 19^{th} century. However, the learning sequence in the original medieval studies partially aligns with its current counterpart; around the 5^{th} century subjects began to be classified as trivium (grammar, rhetoric, and dialectics) and quadrivium (arithmetic, astronomy, geometry, and music).

Therefore, it is hardly surprising that since antiquity the most erudite and learned scholars were familiar with several branches of knowledge and that, in addition to being known as mathematicians, they were also considered to be philosophers, astronomers, physicists, etc. Here we provide a brief historical report of some of the most famous mathematicians of the past who were also celebrated for their expertise in other disciplines.

A Historical Overview

Ancient Greece is, perhaps together with the 19$^{\text{th}}$ century, the most revolutionary period of the history of mathematics. Numerous important Greek mathematicians and philosophers contributed significantly to the development of this branch of knowledge (see Figure 1). Despite the advances in mathematics in previous eras (the Babylonian and Egyptian periods) until the Greeks, mathematics was seen mainly as a practical science: measuring, constructing, counting .... However, the Greeks were concerned with reflecting on the nature of mathematical objects, and with making mathematics a rational and structured science with demonstrable properties (see [3]).

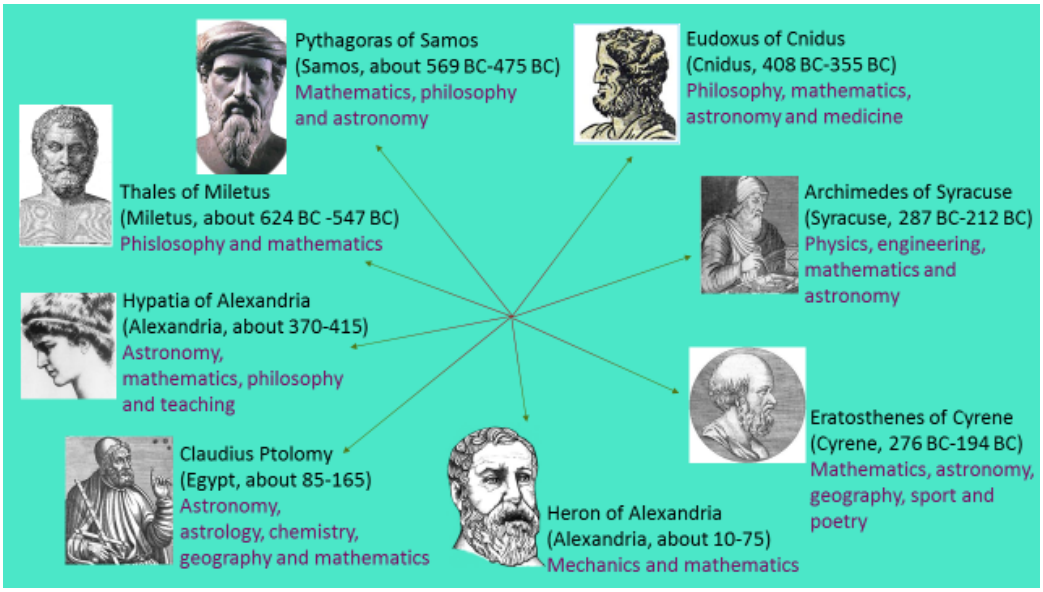

Figure 1: Some multifaceted mathematicians of Ancient Greece. This figure was created from smaller images obtained from `Wikipedia` (`https://www.wikipedia.org`) and the MacTutor History of Mathematics archive [10].

The Middle Ages were essentially marked by the erudition of the Arabs and Persians (see Figure 2) who brought new knowledge, developing and expanding the legacy left by the Greeks [3]. Little by little, during the Early Middle Ages, knowledge and discovery from the Islamic world reached Christian Europe. Moreover, the Classical Period (400-1200) is known as the golden age of Indian mathematics with brilliant results in many areas. One of the major contributions of Indian mathematics was the invention of the zero and the decimal system based on position which reached Europe from India via Arab mathematicians. Chinese mathematicians also made important contributions, a fact often disregarded by many as most Western resources on modern mathematics tend to aggrandize the legacy of the Greeks to the detriment of Indian and Chinese contributions. Unfortunately this report also suffers from the same predicament; most of our references are traditionally Western-centric.

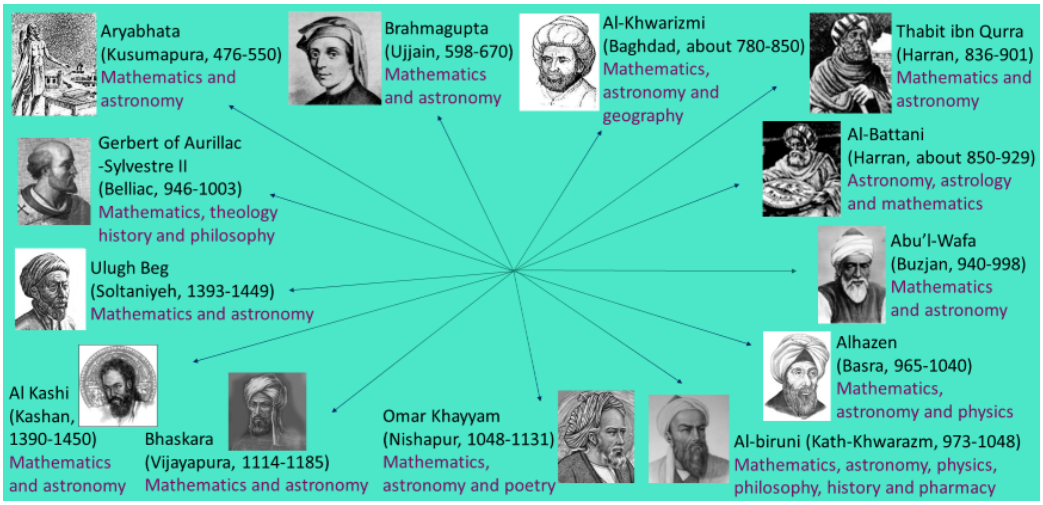

Figure 2: Some multifaceted mathematicians of the Middle Ages. This figure was created from smaller images obtained from `Wikipedia` (`https://www.wikipedia.org`) and the MacTutor History of Mathematics archive [10].

In the 14$^{\text{th}}$ century, a demand for more precise methods emerged in the West with the search for new materials, development of new technologies, navigational needs (due to the many geographical expeditions across long distances in open sea), and the improvement of calculation mechanisms (as trade continued to develop). Furthermore a range of new military problems

came up, following the introduction of gunpowder in Europe (along with problems involving the movement and trajectory of projectiles). At the same time, interactions with other civilisations opened up European culture and the advent of printing enabled knowledge to be widely disseminated.

Thus during the Renaissance (15^{th} and 16^{th} centuries) and the Modern Age (from the mid 15^{th} century to the late 18^{th} century) our focus moves once again back to Europe (see Figure 3). The 16^{th} century in particular marked the advent of modern mathematics when the basics of analytical geometry were established, the concept of function was developed, and infinity was treated in a more systematic manner. During this period, mathematicians were more interested in producing new methods and results than in the rigour of demonstrating their findings (see for example [13]).

Figure 3: Great multifaceted mathematicians of the Modern Age. This figure was created from smaller images obtained from `Wikipedia` (`https://www.wikipedia.org`) and the MacTutor History of Mathematics archive [10].

The 19th century heralded a process of change in which mathematics developed as a formal science independent of the natural sciences. From this century on there was a trend towards specialisation; this resulted in mathematicians concentrating on a few specific areas of mathematics or on one additional science, typically physics or economics. A salient feature of the 19th century was the new rigour imposed on mathematical demonstrations [14]. As a result, this century saw considerable progress in the field of mathematics, arguably exceeding the entire production of all the previous ages in terms of quality and quantity. Around this time, important new academies and associations were created, such as the London Mathematical Society (1865), la Société Mathématique de France (1872), and the American Mathematical Society (1888), among others, which were instrumental in legitimising the profession of mathematician in society. Some polymath mathematicians of the 19th century can be seen in Figure 4.

Figure 4: Great multifaceted mathematicians of the 19th century. This figure was created from smaller images obtained from `Wikipedia` (`https://www.wikipedia.org`) and the MacTutor History of Mathematics archive [10].

In the 20th century mathematical production continued to grow at an exponential rate and mathematics became a real profession. In 1900, in a speech at the International Congress of Mathematicians, David Hilbert (Wehlau, 1862-1943) established a list of twenty-three unsolved problems which were to occupy many mathematicians for most of the 20th century. At the present

time, nearly all the correctly formulated problems have been solved or partially resolved; only two remain unsolved (including the Riemann hypothesis which is one of the seven Millennium Problems [4]). This century also saw the development of computers, and mathematical methods had considerable impact in many disciplines. Many problems remain open for the 21st century; these will surely lead to major, surprising contributions to mathematics.

Disciplines of Expertise That Exploit Natural Synergies

The main fields of non-mathematical expertise of the mathematicians we explored in the preceding pages seem to be astronomy, philosophy, and physics.

Astronomy

Astronomy uses observation and calculation. The systematic use of mathematics in astronomical investigation has led to tremendous successes and has enabled the results of studies in this field to be expressed in precise language, thus permitting discovery of the most important laws of nature. Perhaps due to this natural connection, the list of recognised mathematicians who were also astronomers is long. Figure 5 shows, from our point of view, the most representative individuals who in some cases are better known to the general public as astronomers than as mathematicians.

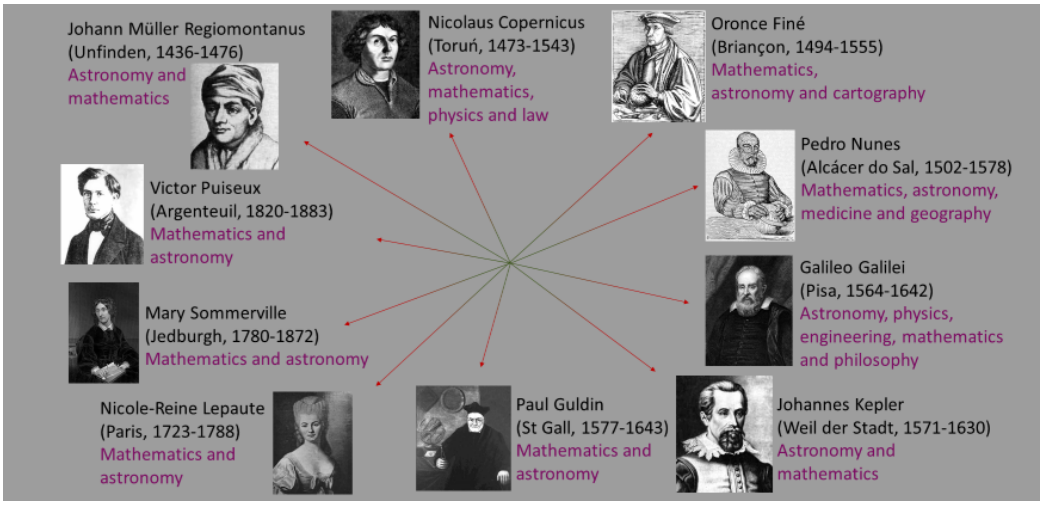

Figure 5: Some relevant mathematician astronomers. This figure was created from smaller images obtained from `Wikipedia` (`https://www.wikipedia.org`) and the MacTutor History of Mathematics archive [10].

In antiquity Pythagoras and the classical Greeks were already teaching that the Earth was round and was the centre of the universe and that the Moon's orbit was inclined towards the Earth's equator. Nicholas Copernicus broke with this central view of our planet, placing the Sun at the centre of the Universe. Galileo, whose main contribution to astronomy was the use of the telescope, confirmed Copernicus' work.[1] Subsequently, Kepler embraced the study of the planets' orbits and attempted to use Platonic solids in order to discover the solar system. These studies led to the formulation of three laws, which were also used by Johann Carl Friedrich Gauss (1777-1855) to predict the reappearance of an asteroid. Newton also used Kepler's laws, together with infinitesimal calculus, in order to pronounce the law of universal gravitation. This permits equations to be written which govern the movement of celestial bodies, and also the movement of satellites and spacecraft.

Another name worthy of mention in this section is Hypatia, the first woman known to have made an important contribution to mathematics. Among these contributions was the improvement and construction of astronomical instruments such as the astrolabe or the planisphere.[2]

Questions relating to the shape of the Earth, estimation of its radius, determination of the planetary trajectories around the Sun, and measurement of a meridian degree required mathematical knowledge in the corresponding eras in which they were studied. Solutions to these problems led to tremendous scientific progress and the development of new theories. In 1734, a scientific commission was sent by the king of France Louis XV, to measure the meridian in the vicinity of the Equator and rectify the true shape of the Earth [12]. This first expedition was aided by some multifaceted mathematicians such as Pierre Bouguer (Le Croisic, 1698-1758), mathematician, astronomer, and hydrographer, Charles Marie de la Condamine (Paris, 1701-1774), mathematician, naturalist, and geographer, and Jorge Juan y Santacilia (Novelda, 1713-1773), mathematician, naval officer, and mariner. The second expedition travelled to Lapland in 1736-1737 with Pierre Louis Maupertuis (Saint Malo, 1698-1759) in charge (he was a mathematician, physicist, astronomer, and philosopher) accompanied by scientists Alexis Claude Clairaut (Paris, 1713-1765), mathematician and astronomer, also known for the equation

[1] Readers may find of interest the two feature films made of Galileo's life: Liliana Cavani's *Galileo Galilei* (1968) and Joseph Losey's *Galileo* (1974), see [11].

[2] Alejandro Amenábar's film *ágora* (2009) may be of interest to the readers, see [6].

named after him, and the mathematician and astronomer Charles Étienne Louis Camus (Crécy-en-Brie, 1699-1768). The results confirmed Newton's theory that the Earth was an ellipsoid in revolution, flattened by the poles. Measurement of the meridian had enormous social repercussions.

Philosophy

From the time of the Pythagoreans, mathematicians have been concerned with the basis of their chosen discipline, raising innumerable perplexing questions. Philosophers have also been interested in mathematics which has played an important role in many philosophical explanations. In this regard, from the study of philosophy and mathematics arose some of the first intellectual attempts at understanding the material world, as part of the quest for knowledge which flowered in ancient Greece.

For example, Descartes, Pascal, and Leibniz were brilliant mathematicians in the 17^{th} century whose philosophical contributions are clearly marked with the impromptu style of the mathematician. Cartesian coordinates in a plane which were named after the philosopher mathematician René Descartes (deriving from his Latinised name Renatus Cartesius), associate each point on the plane with a number pair denominated as abscissa and ordinate and they establish a duality between algebra and geometry so that a geometric problem can be addressed in two alternative ways. Another famous philosopher and mathematician Pascal established, together with Fermat, the principles of probability theory but he is also known for the pascaline (1642), a forerunner of today's computer and one of the first mechanical calculators, which functioned on the basis of wheels and gears. Leibniz, together with Newton, developed infinitesimal calculus and introduced various notations used today such as that of the integral sign and the letter d to refer to differentials. Furthermore, the rule of the nth derivate of a product of functions is known as the Leibniz rule or formula.

Famous mathematician philosophers of recent years include Cantor, Peano, and Poincaré in the 19^{th} century, and Hilbert, Russell, Whitehead, Wittgenstein, and Gödel in the 20^{th} century (see Figure 6). Cantor, despite a life marred by fits of depression, concentrated on the study of extremely abstract themes. In particular, his study of infinites led him to formulate the Continuum Hypothesis in 1878 which states that there are no intermediate cardinalities between the size of natural numbers and the size of real numbers. He also proved in 1877 that it was possible to establish a bijection between

the unit square and the unit interval $[0, 1]$. In relation to this discovery, in 1890 another mathematician-philosopher, Peano, provided the first example of continuous curve filling the plane, an early example of what we now know as a fractal. Gödel was inspired by Cantor's work and demonstrated that mathematical completeness was unattainable as there would always be statements which, although they were true we could not demonstrate. Poincaré, considered the creator of modern topology, in addition to disseminating the science through various works, is especially known for the Poincaré conjecture (now a theorem) which establishes that if a space has the same topological properties as a sphere it must be a sphere.

Other mathematicians such as Blaise Pascal, María Gaetana Agnesi, and Johann Karl Friedrich Gauss also studied theology, which is historically related to philosophy.

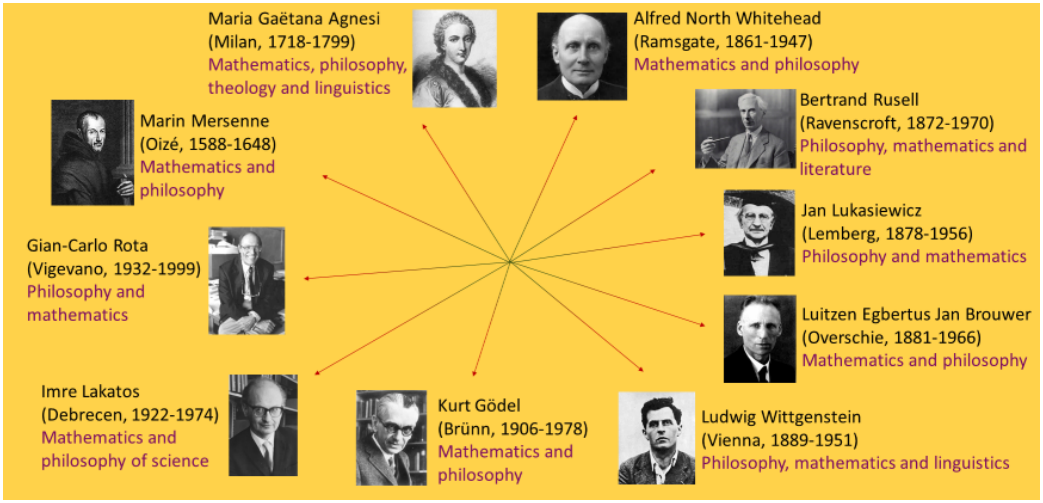

Figure 6: Some well-known mathematician philosophers. This figure was created from smaller images obtained from `Wikipedia` (`https://www.wikipedia.org`) and the MacTutor History of Mathematics archive [10].

Physics

Many areas of mathematics were developed largely due to the stimulus provided by physical problems. For example, differential calculus and differential equations generated enormous interest after they had been used by Newton in the formulation of the famous Newton's laws. Variational calculus began

with an attempt to resolve some physical problems such as the brachistocrone problem raised in the late 17^{th} century. Riemann's geometry gained considerable interest when Albert Einstein (Ulm, 1879-1955) used it in his general theory of relativity. Furthermore, Newton and Leibniz' work on infinitesimal calculus provided the mathematical tools for developing physics as a science able to make predictions.

The prolific Leonhard Euler is a significant example of a mathematician also considered to be a physicist. Hampered by a partial loss of vision before he was 30, and by almost total blindness by the end of his life, Euler produced almost half of his work thanks to his extraordinary memory and the help received from those close to him. In 1736, Euler solved the problem of the Königsberg bridges, in the city of that name, today a part of Russia, and which had two large islands with a total of seven bridges, where the question was deciding whether it was possible to follow a path by crossing all the bridges just once and arriving at the point of departure. Euler managed to demonstrate mathematically that there was no such path, which is considered to be the first theorem in graph theory. Euler also introduced the concept known as Euler's characteristic of space and a formula which related the number of sides, vertices and faces of a convex polygon with this constant. Furthermore what is considered to be the most beautiful formula in mathematics, $e^{i\pi} + 1 = 0$, is also known as Euler's identity. This formula relates trigonometry with mathematical analysis.

Emmy Noether is considered by many to be the most important woman in the history of mathematics. Indeed Noether, with students, developed much of modern algebra, and today, many mathematical concepts associated with algebra are named after her. Noether is also well-known for what is today called Noether's theorem, a fundamental tool for theoretical physics and mechanics, which states that the differentiable symmetry of the action of a physical system (transformations which leave the system invariant) has a corresponding conservation law.

Two mathematicians who are perhaps better known as physicists are Doppler and Ohm. The former is associated with the so-called Doppler effect: the apparent change of frequency of a wave produced by the movement relating to the source with respect to its observer. Sound is more acute close by and deeper when further away. The latter gave his name to the ohm, the unit of electrical resistance in the international system, and Ohm's law which states

that the current through a conductor between two points is directly proportional to the potential difference across the two points, thus introducing a constant of proportionality called resistance.

In any case, the list of recognised mathematicians who were also considered to be physicists is also long. Some representative examples are shown in Figure 7, but there are many other recent names such as Mary Taylor Slow (Sheffield, 1898-1984), Phyllis Nicolson (Macclesfield, 1917-1968), Yvonne Choquet-Bruhat (Lille, 1923-), and Edward Witten (Baltimore, 1951-).

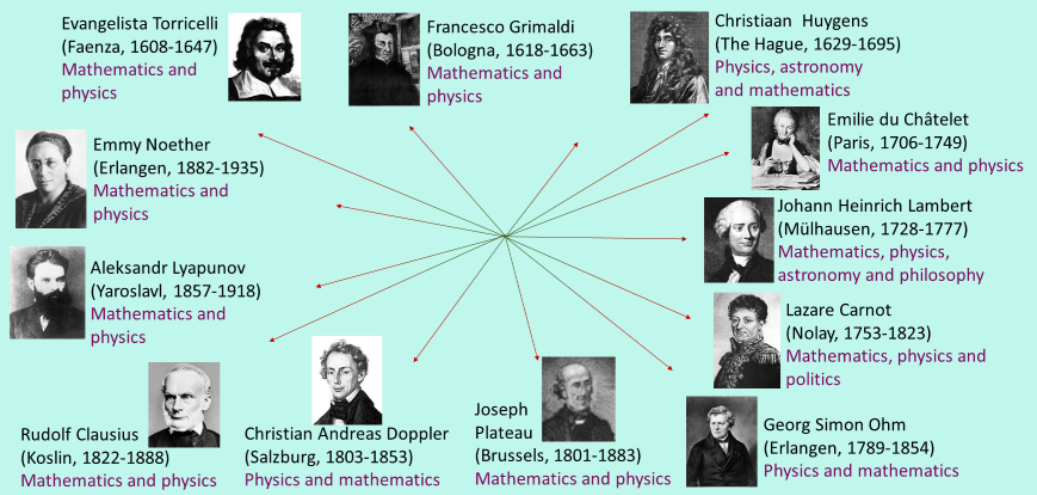

Figure 7: Some representative mathematician physicists. This figure was created from smaller images obtained from `Wikipedia` (`https://www.wikipedia.org`) and the MacTutor History of Mathematics archive [10].

Engineering

Mathematics has been a fundamental tool in the scientific world, in daily life, and in our continuing search for subsistence; the latter led to the development of diverse bodies of knowledge that we call engineering today. Thus, it would be remiss not to mention some famous mathematician-engineers.

Archimedes of Syracuse is often considered to be the first applied mathematician in history, as he was particularly interested in the practical aspects of mathematics. The most famous anecdote attributed to him involves him determining whether a gold crown commissioned by Heiro II, king of Syracuse

who was Archimedes' patron, had been fraudulently made. Apparently there was some concern over whether or not the goldsmith had added silver to the crown and kept part of the gold for himself. When he was in a bath house, legend has it that Archimedes noted that the amount of water overflowing from the bath was equal to that being poured into it. So overjoyed with his discovery, he ran naked through the streets of Syracuse to his home shouting *Eureka* (I found it!). Another anecdote concerning Archimedes, to whom we owe the law of the lever, refers to his statement before Heiro that if he was given a place to stand on he would move the Earth. He also used the so-called method of exhaustion to determine that the volume of a sphere is two thirds of the volume of the circumscribed cylinder, a result which was engraved on his tomb and which the International Mathematical Union includes on the reverse of the Fields medals.

Heron of Alexandria was a Hellenistic mathematician and engineer in Alexandria. He wrote various treaties on mechanics and his work is representative of the Hellenistic scientific tradition. However, he is best known for his results in the field of geometry, for example for the formula named after him which calculates the area of a triangle based on the length of its sides.

Rafael Bombelli (Bologna, 1526-1572) was a Renaissance mathematician with an interest in the roots of polynomic equations. He was also known as a hydraulic engineer. He used continuous fractions to calculate square roots.

We should also mention that other sciences considered in some eras as areas of engineering have been developed thanks to the contributions of great mathematicians. For example, early cybernetics is inextricably linked to the prolific and productive research of the American mathematician Norbert Wiener (Columbia, 1894-1964) in collaboration with other scientists from the beginning of the Second World War. In this same realm Alan Mathison Turing (London, 1912-1954) is considered to be one of the fathers of computer science and the precursor of modern information technology. During the Second World War he worked at deciphering Nazi codes, particularly those of the Enigma machine. The mathematician and computer expert Hermann Goldstine (Chicago, 1913-2004) should also be included in this section, as one of the main developers of ENIAC, the first general purpose digital electronic computer [8]. In the same way, we mention the mathematician, computer scientist, and philosopher Hilary Putnam (Chicago, 1926-2016), known by the so-called Davis-Putnam algorithm for the Boolean satisfiability problem.

Other prominent names include Jean-Victor Poncelet (Metz, 1788-1867), Gaspard Coriolis (Paris, 1792-1843), and Irmgard Flügge-Lotz (Hamelin, 1903-1974) who were mathematicians and engineers; Charles Babbage (London, 1791-1871), mathematician, philosopher, inventor, and mechanical engineer; Leonid Kantorórich (St Petersburg, 1912-1986), economist, mathematician, and engineer; and Aleksey Krylov (Visyaga, 1863-1945), a naval engineer and mathematician.

Economics

We wish to add economics to our list of typical fields of non-mathematical expertise, as its relationship with mathematics has clearly grown over the last century. Much of economic theory is represented in terms of economic models, a set of simple and elegant mathematical relations conceived to clarify suppositions and implications deriving from the same. Economics began to be mathematised early in the 19^{th} century, and with the onset of the 20^{th} century, a collection of new mathematical tools were developed, deriving from differential calculus, differential equations, convex sets, and graph theory in order to advance economic theory in a manner similar to new mathematical models previously applied to physics.

The work of mathematician economists who have received Nobel Prizes for their research in economics has carved out a path in their field which has been followed by many. One such pathbreaker is John Nash who, despite battling with schizophrenia was celebrated for his contributions to game theory.[3] His enormous creative activity made him one of the most celebrated mathematicians of his generation, and he received widespread recognition before his untimely death in a traffic accident in which his wife also perished. The Nash equilibrium in game theory is the stable state of a system involving the interaction of different participants, in which no participant can gain by a unilateral change of strategy if the strategies of the others remain unchanged. In this regard we recommend learning more about the prisoner's dilemma, the archetypal example par excellence of the Nash equilibrium, in which to confess is a strategy that is always dominant for both suspects. This is surely a dilemma with which the renowned Greek economist, professor, and writer Yanis Varufakis (Athens, 1961-), trained in mathematics and statistics must

[3]Many readers may well associate him with Ron Howard's film *A beautiful mind* (2001), based on his life [9].

have been acutely familiar, as he was obliged to face a dilemma of this kind in 2015 when, in his capacity as Minister of Finance, he had to deal with the tumultuous weeks during which Greece sought credits which would help them escape the mess the country had plunged into.

Another well-known English mathematician economist was David Gawen Champernowne (Oxford, 1912-2000), who has a constant named after him, $C = 0,12345678910111213141516\ldots$, the main characteristic of which is that the probability of finding a given sequence of digits throughout its decimal expansion is the same as it were to seek another sequence of the same amount of digits.

Great Sportsmen who were also Mathematicians

In recent years there has been a proliferation of research and investigation into creating mathematical models for optimising aspects of sports. In fact, sports entail significant analysis, decision, strategy, and problem solving. However, the connection between mathematics and sports is not restricted to the prominent presence of exact sciences in the study of various sporting disciplines; we have found a significant number of players who are also mathematicians notable for their brilliant performance in the world of sports.

Alan Mathison Turing (London, 1912-1954)[4] was, as mentioned above, a distinguished mathematician, but he was also a fanatical long distance runner. He became an expert at marathons; his record in 1949, aged 37, was approximately 2 hours and 45 minutes, which was only 10 minutes slower than the Olympic champion of that era. Turing was a member of Walton Athletic Club, winning their 3-mile and 10-mile championship in record time [10].

Harald August Bohr (Copenhagen, 1887-1951) was an eminent mathematician who introduced the almost periodic functions, a powerful theory determined to study the asymptotic distribution of zeros of those functions.[5] It is said that, despite the enormous merit of his mathematical achievements, Harald was actually more well-known for his prowess as a football player.

[4] A neat film about Turing is *The imitation game* (Morten Tyldum, 2014).

[5] His brother Niels Bohr (Copenhagen, 1885-1962) won the Nobel Prize for physics in 1922, and contributed much to the understanding of the structure of the atom and quantum mechanics.

In fact, Harald Bohr was a member of the Danish national football team in the 1908 Olympic Games where he won a silver medal [1].

Competitive chess is considered to be a sport by the International Olympic Committee; in addition to being totally structured and regulated, the game is based on strategy and tactics. Where chess is concerned, mention of Emanuel Lasker (Berlinchen, 1868-1941) is inevitable; a German chess player, mathematician, and philosopher, he was champion of the chess world from 1894 to 1921. His main contribution to mathematics was in the field of abstract algebra. Machgielis Euwe (Watergraafsmeer, 1901-1981) was another notable mathematician and chess player who was world champion from 1935 to 1937. In addition, the recreational mathematician Samuel Loyd (Philadelphia, 1841-1911), at the height of his fame was one of the best American chess players at the top of the world game.

Then we have mathematics used as a metaphor for successful strategy in sports and sports used as a metaphor for prowess in mathematics. For example, the ex-football player Ottmar Hitzfeld (Lörrach, 1949-) was a trainer of some of the most successful football teams in the world. In public, Hitzfeld was known as the mathematician of football tactics. In fact, he graduated as a teacher of mathematics and sports, so there is a real connection with mathematics there. But in the case of our next example, the connection seems to have been merely metaphorical.

Eratosthenes, in the 2nd century BC, is believed to be one of the most versatile scientists of the Ancient World. He is today well-known for having obtained a measurement of the Earth's perimeter (comparing the longitude of the shadow of a stake in different cities) and for the Sieve of Eratosthenes, a systematic method of obtaining prime numbers. For all those talents Eratosthenes was nicknamed Pentathlon, i.e., a sportsman who participated simultaneously in competition in several sportive contests: 180 metre race, wrestling, long jump, javelin throwing and discus throwing [7]. It is not known if indeed Eratosthenes had any athletic inclinations, however.

Other Less Common Relationships with Mathematics

This section lists other fields which, like sports, seem to have rarer overlaps, due to the difficulty in discovering great mathematicians who share their mathematical vocation with these other disciplines (see also [16]).

Pierre de Fermat (Beaumont-de-Lomagne, 1601-1665) was one of the foremost mathematicians of the first half of the 17$^{\text{th}}$ century. In reality he was a lawyer. However, his mathematical works, particularly in the theory of numbers, were notable for their brilliance. Fermat's Last Theorem conjectured by Fermat in 1637 took considerable time to be finally demonstrated, and it was not until 1995 that the English mathematician Andrew Wiles (Cambridge, 1953-), using modern mathematical techniques with a high degree of abstraction, was able to do so [17].

Concerning politics, Ulisse Dini (Pisa, 1845-1918), known for his contribution to real analysis and in particular for the so-called Dini criterion for the convergence of Fourier series, was an Italian mathematician and politician who became a member of the Italian parliament in 1880. More recently, the well-known mathematician Cédric Villani (Brive-La-Gaillarde, 1973) was awarded the Fields Medal in 2010, and in 2017 he was selected as a member of the National Assembly for En Marche! in the French legislative election. We can also cite two US presidents: James A. Garfield (Orange, 1831-1881), who was an amateur mathematician, and Thomas Jefferson (Shadwell, 1743-1826) who had great knowledge of mathematics, metaphysics and philosophy. Garfield, some may know, published an original proof of the theorem of Pythagoras.

Charles Lutwidge Dodgson (Daresbury, 1832-1898), better known by his pseudonym Lewis Carroll, was a renowned British mathematician, photographer, and writer who was also a church deacon. His best known works are *Alice in Wonderland* and *Alice through the Looking Glass*. Most of his mathematical work was concerned with geometry, however he wrote on various mathematical themes such as, for example, the paradox of Achilles and the tortoise. On the other hand, the novelist and writer Bram Stoker (Clontarf, 1847-1912), author of *Dracula*, graduated in mathematics and science at Trinity College where he excelled as an athlete. Another mathematician writer was Charles Howard Hinton (London, 1853-1907) who was especially interested in the fourth dimension. Tommaso Ceva (Milan, 1648-1737) was also a noted poet and mathematician and dedicated a significant amount of his time to this task. William Brouncker (Castlelyons, 1620-1684), the first President of the Royal Society, was an English mathematician and linguist. More recently, Piet Hein (Copenhagen, 1905-1996) was a Danish scientist, mathematician, inventor, designer, author, and poet.

Miguel de Unamuno y Jugo (Bilbao, 1864-1936) was a Spanish writer and philosopher attracted by mathematics or rather, the beauty of mathematics. Some of his poetry was mathematical, see for instance Cancionero 225. Jorge Luis Borges (Buenos Aires, 1899-1986) was another writer who, among other mathematical connections, addressed modern theories of quantum mechanics in his work and mentioned the Fibonacci sequence. Arthur Conan Doyle's famous fictional character Moriarty, the implacable enemy of Sherlock Holmes, is also worthy of note. Doyle makes his character visibly a mathematician. In this section we can also mention the writer and theologian Edwin Abbot (Marylebone, 1838-1926), author of *Flatland: A Romance of Many Dimensions*; the writer and director Apostolos Doxiadis (Brisbane, 1953-), author of didactic novels like *Uncle Petros and Goldbach's conjecture*; and Paolo Giordano (Turin, 1982-), a polymath with a degree in theoretical physics and author of *The Solitude of Prime Numbers*.

Mathematical contributions to medicine have helped enormously in technical developments in the field. However, long before the present day there were great mathematicians who were also doctors. Paolo Ruffini (Valentano, 1765-1822), before becoming a professor and explaining the fundamental precepts of analysis, was a physician and surgeon. Ruffini's rule which is used in the division of polynomials when the dividing polynomial is a binomial of the form $x - a$, is the most well known mathematical result that bears his name. Other mathematicians who were also medical doctors were Gerolamo Cardano (Pavía, 1501-1576), Adriaan Van Roomen (Leuven, 1561-1615), and Jan Brozek (Kurzelów, 1585-1652).

As powerful mathematical methods were developed in order to analyse experimental results, the world of mathematics has also coincided with the fields of biology and chemistry. D'Arcy Wentworth Thompson (Edinburgh, 1860-1947) is considered to be the first bio-mathematician in history (as he was both a biologist and a mathematician). His observations on phyllotaxis (numerical relations between spiral structures in plants) and the Fibonacci sequence have become basic premises over time.

Dorothy Maud Wrinch (Rosario, 1894-1976) was a biochemical theorist as well as a mathematician, best known for her attempt at deducing the structure of protein using mathematical principles; for a personal read on Wrinch see [15].

Frederick Soddy (Eastbourne, 1877-1956), awarded the Nobel Prize in Chemistry, was an English chemist and university professor who was also dedicated to problem solving in mathematics, economics, and quantum mechanics. Georges-Louis Leclerc (Montbard, 1707-1788), Comte de Buffon, was a naturalist, botanist, biologist, cosmologist, writer, and mathematician. He is remembered in mathematics by the classic problem of Buffon's needle in theory probability, in which a needle is cast on a paper so that if we draw parallel lines equally spaced and with distance equal to the length of the needle, then the probability that the needle crosses one of the lines it is $2/\pi$. John Anthony Pople (Burnham-on-Sea, 1925-2004) graduated in mathematics in 1946 and gained his doctorate in chemistry in 1951. He was awarded the Nobel Prize for Chemistry in 1998.

We next list other multifaceted mathematicians who were also experts in various fields: Xu Guangqi (Shanghai, 1562-1633), mathematician, astronomer, and agricultural scientist; Jean-Charles de Borda (Dax, 1733-1799), mathematician, physicist, political scientist, and sailor; Jurij Bartolomej Vega (Zagorika pri Dolskem, 1754-1802), mathematician, physicist, and artillery officer; William Wallace (Dysart, 1768-1843), mathematician, astronomer, and inventor; Franz Ernst Neumann (Joachimsthal, 1798-1895), mineralogist, physicist, and mathematician; Christine Ladd-Franklin (Windsor, 1847-1930), psychologist, logician, and mathematician; and Maria Reiche (Dresden, 1903-1998), mathematician, archaeologist, and technical translator.

Artists Linked to Mathematics

The list of artists (painters, sculptors, architects, photographers, composers) who actively explored mathematics in some of their works is enormous; perhaps science and art are not quite so disparate as is often thought. Indeed [5] explains in detail and with many examples how art and mathematics have been intertwined throughout the history of humanity. In what follows we explore such connections, mainly through a list of distinguished artists who may also be labeled (at least honorary) mathematicians.

One notable artist and mathematician par excellence is Maurits Cornelius Escher (Leeuwarden, 1898-1972). Despite his limited mathematical training, mathematics is everywhere in Escher's work; he makes use of ideas such as tessellation, polyhedra, Moebius strip, non Euclidean geometry, and fractals in many of his woodcuts, lithographs, and other works [2].

Several artists used the golden proportion or other mathematical elements both in the format of their canvases and as the main elements of their works. This is the case with Leonardo Da Vinci (Vinci, 1452-1519), painter, artist, architect, sculptor, musician, and philosopher, and some of his most famous works such as *The Vitruvian man*, *The Mona Lisa*, and *The Last Supper*. Similarly, Salvador Dalí (Figueres, 1908-1994), painter, sculptor, engraver, scenographer, and writer, in works such as *Giant Flying Demi-Tasse with Incomprehensible Appendage Five Meters Long* and *Leda atómica*, synthesises centuries of mathematical and symbolic tradition.

An example of organisation through the pentagonal star is *The Holy Family* by the Renaissance painter Michelangelo Buonarroti (Caprese, 1475-1564) who was, moreover, an architect and sculptor. Another artist who was enamoured of mathematics was Albrecht Dürer (Nürnberg, 1471-1528), who used the harmony and beauty of the golden number to represent Adam and Eve. Dürer also wrote a book in which he endeavoured to teach artists, painters, and mathematicians of the era various methods for tracing different geometric figures. In this respect it is important to mention that Piero della Francesca (Borgo San Sepolcro, 1420-1492) and Luca Pacioli (Sansepolcro, 1445-1517), who wrote *De divina proportione* which was illustrated by Da Vinci, were mathematicians who wrote books on mathematics in art. The painter Tobia Ravà (Padova, 1959), known as the Pythagorean modern, keeps the number as a vehicle in many of his works.

Even the painter Diego Velázquez (Seville, 1599-1660) used the golden section in his painting *Las Meninas*, one of his most famous works. Most recently, the artist Mario Merz (Milan, 1925-2003) was also obsessed with the terms of the Fibonacci sequence and, similarly, the photographer Henri Cartier-Bresson (Chanteloup-en-Brie, 1908-2004) was fascinated by spirals. Another multifaceted mathematician-author was Leon Battista Alberti (Genoa, 1404-1472), artist, architect, poet, linguist, philosopher and cryptographer. Other names of artists linked to this discipline are Ómar Rayo (Roldanillo, 1928-), Eduardo Moisset de Espanés (Córdoba, 1932-), Eugen Jost (Zürich, 1950-) and Beatriz Milhazes (Rio de Janeiro, 1960-).

Ernö Rubik (Budapest, 1944-) is a sculptor, architect, and designer; we can certainly declare him an honorary mathematician as Rubik invented the famous Rubik's cube, which has no less than 43,252,003,274,489,856,000 possible positions. There are many algorithms for solving it, in particular, the

so-called God's algorithm which specifies the fewest number of movements to reach the solution from any departure point of the cube, namely a maximum of 20 movements.

Antoni Gaudí (Reus, 1852-1926), who designed the Sagrada Familia cathedral, was a famous architect who used the catenary as a characteristic element. Le Corbusier (Le Chaux-de-Fonds, 1887-1965), architect, engineer, designer, and painter externalised the beauty of the golden proportion of nature and used it in his architectural works. Other contemporary sculptors and architects who manifested a special relation with mathematics are John Robinson (London, 1935-2007), Max Bill (Winterthur, 1908-1994), and Mario Botta (Mendrisio, 1943-). Certainly, one of the few cases of mathematicians (and so perhaps he should not be included in this section) who makes a living from sculpture is Rinus Roelofs (Hengelo, 1954-), who is also known for having detected errors in one of Da Vinci's drawings which represents a rhombicuboctahaedron.

On the other hand, Arthur Ira Garfunkel (New York, 1941-) is a famous American singer and actor well known as half of the folk duo Simon and Garfunkel, who were popular in the sixties. Garfunkel was passionate about mathematics and even taught the subject in a number of different New York schools. On the other hand, David Krumholtz (Queens, 1978-) has had no training in mathematics but as an actor he brought to life Charlie Eppes, a young genius mathematician who works as an FBI advisor in the series Numb3rs (CBS, 2005-2010) which was awarded the Carl Sagan prize for public understanding of science. Philip Morris Glass (Baltimore, 1937-) studied mathematics and he is considered one of the most influential music makers of the late 20^{th} century. The musician Brian May (Hampton, 1947-), from the successful British band Queen, is also an astrophysicist. Esperanza Spalding (EEUU, 1984-) is a singer, bass player, and jazz bassist who spreads the connection between music and mathematics.

In the world of film and television we also mention some names of graduates in mathematics: the actors Dan Grimaldi (Brooklyn, 1950-), known for his role in *The Sopranos*; Robert Altman (Kanssa City, 1925-2006) who got an honorary Oscar; Danica McKellar (La Jolla, 1975-), who starred in the popular series *The Wonder Years*; Masi Oka (Tokyo, 1974-), actor and digital effects artist who has a professorship in mathematics; Omar Sharif (Alexandria, 1932-); and James Wilby (Rangoon, 1958-). Moreover, among

the writers of some animated sitcoms like *The Simpsons* and *Futurama* there are graduates and PhDs in mathematics, physics, and computer science, we highlight the names of the American producers Ken Keeler (1961-), Al Jean (1961-), and James Stewart Burns. In addition, before writing novels, the screenwriter and novelist Curt Siodmak (Dresden, 1902-2000), who was behind *The Wolf Man*, graduated in mathematics. Also some film directors who graduated in mathematics are Sergei Loznitsa (Baranovichi, 1964-), Paul Verhoeven (Amsterdam, 1938-), Shane Carruth (Myrtle Beaach, 1972-), and Dany Saadia (Mexico City, 1969-). Another known actor, Dolph Lundgren (Stockholm, 1957-), who played Ivan Drago in *Rocky IV*, won a scholarship in mathematics at the Massachusetts Institute of Technology.

To conclude, let us look at the world of magic. Raymond Smullyan (New York, 1919-2017) was an American mathematician, concert pianist, logician, philosopher, and magician. Other names are Persi Diaconis (New York, 1945-) and Ronald Graham (California, 1935-) who are known for tackling mathematical problems involving randomness and randomization and also for the mathematical ideas that animate great magic tricks. Finally we must mention Martin Gardner (Tulsa, 1914-2010), American expositor of mathematics, whose other interests included magic and illusion, as well as puzzles.

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