The Swedish Archimedes

The Formation of the Polymath Christopher Polhem

Dunér, David

Published in:
Rethinking Stevin, Stevin rethinking

DOI:
10.1163/9789004432918_005

2020

Document Version:
Peer reviewed version (aka post-print)

David Dunér

The Swedish Archimedes
The formation of the Polymath Christopher Polhem

Introduction: Polhem's Headache

When the Swedish mechanicus and natural philosopher Christopher Polhem (1661–1751) was thinking too much, he felt that his brain became sore and aching.[1] The body became weak and powerless of all thoughts that he never had before. But nevertheless, he constantly searched for new knowledge about the world: the laws of mechanics, the inner structure of matter, the movement of water, the geological processes, and the waves of sound and light. He tried to understand the world, interpret it, think about it, tried to invent new things, and build models of reality. He made contributions to engineering, mechanics, physics, matter theory, geology, mathematics, linguistics, music theory, economic theory, and much more. He was a polymath.

As a polymath Polhem transgressed the established and imagined disciplinary borders of knowledge. But what makes him a polymath is foremost a certain kind of combinatory quest, i.e., the transdisciplinary cohesion of theory and practice. This "Archimedean polymathy" is characterized by the strive for and need of both theoretical understanding and practical experience, both mathematics and craftsmanship, rational and empirical approaches, in order to solve technological problems. Experience and knowledge of craftsmen should be combined with the mathematical, analytical mind of the learned natural philosopher. For a machine to be applicable one needs the practical experience of a craftsman *and* the analytical insights of a mathematician. Polhem himself again and again emphasized the need of a necessary unification of theory and practice. His compatriots used to call him "the Swedish Archimedes", referring to his rare transdisciplinary skills as an inventor, a craftsman-mathematician who could combine the delicate theoretical sagacity of a mathematician and the wide, longstanding and tangible practical experience of a craftsman. Polhem's "Archimedean polymathy" was in that sense not a strive to be universally knowledgeable, to obtain encyclopaedic knowledge for its own sake, but to combine practical experience with theoretical analysis for solving specific technological problems, to improve and enhance human creativity.

---

[1] Polhem 1941–46, p. 36.

In this combinatory strive for theory and practice, Polhem reminds to a great extent of Simon Stevin's blending of theory and praxis, in his use of mathematical sciences in technology, for example in statics and hydrostatics. For Polhem a theoretical and mathematical approach to statics and hydrostatics was the key to the practicability of mining machines, water mills, locks and dams, and many other technological enterprises. Like Stevin, Polhem focused on engineering and mathematics, but also had great interest in linguistics and music, much less in medicine and botany. Polhem and Stevin alike were interested in the nature and structure of knowing. Religion, however, is almost completely absent in both Stevin's and Polhem's works. As in the case of Stevin, Polhem lacked the linguistic foundation for polymathy, Latin proficiency, but as Stevin he had the theoretical-mathematical skills of a true Archimedean polymath of the early modern period, in Polhem's case: skills in algebraic mathematics, insights in calculus, and the predilection to natural philosophical speculations. Polhem's Archimedeanism could also be compared to the Vitruvianism of Joseph Furttenbach the Elder,[2] as being knowledgeable in both practical and theoretical matters concerning architecture, to become a universal architect of the Vitruvian ideal. Polhem however clearly transgressed the disciplinary borders, and did not seek to be universally knowledgeable for its own sake. The focus of his polymathy lies rather in finding the balance between theory and practice.

Stevin, as E. J. Dijksterhuis put it, "continually oscillated between what he called *spiegeling* (speculation, *i.e.* theoretical investigation) and *daet* (practical activity)."[3] This oscillation between theoretical investigation and practical activity is very much also Polhem's Archimedean exertion. This chapter delves into the question of the formation of such an Archimedean polymath, the craftsman-mathematician. Polhem can be seen as a case of how polymathy could be obtained, through education and the use of abilities such as perception and communication, but also the social factors forming polymathy. The following sections discuss Polhem's professional formation, through formal education, perception, and communication. Before these sub-themes, a recapitulation of Polhem's major technological achievements would be appropriate.[4]

The Swedish Archimedes

Many of Polhem's most famous and innovative machines were constructed

---

[2] See Lazardzig's chapter in this volume.
[3] Dijksterhuis 1970, p. 130.
[4] Lindroth 1951; Bring 1963; Dunér 2010; Lindgren 2011.

for the Stora Kopparberg mine in Falun in central Sweden. As the major copper mine in Sweden technological improvements were a necessity for the economy of the Swedish state. Polhem became responsible for the machines at the mine and was engaged for its improvements for more than 20 years. Most notably, he designed and constructed machines for hoisting the ore from the pit (Figure 1). Without previous knowledge and experience of mining, he approached the mechanical problems in a new fashion, independently of the long-lasting traditions of miners and craftsmen. It might be described as a sort of "genial ignorance" when a person coming from the outside trying to solve a problem without the knowledge of the experienced expert, which turns out – contrary to the expectations – to lead to a successful solution. Ignorance sometimes liberates the mind, let the problem-solver fearlessly approach the task with other, non-traditional methods. Polhem, for example, replaced costly and less durable leather ropes with pairs of wooden rods where the barrels climbed from a pair of hooks to another.

Polhem lived in a time of increased trade, followed by more frequent international contacts, when the Swedish state in line with mercantilist economic doctrines endorsed and subsidised a domestic processing industry. In 1700, Polhem started together with the lawyer Gabriel Stierncrona a mechanical manufacturing works in Stjärnsund in southern Dalecarlia. The proto-industrial Stjärnsund works began a large-scale production of various utensils, cups, bowls and plates of tinned iron plate; it manufactured bells, locks, agricultural equipment and tools for carpenters, tinsmiths, blacksmiths and other craftsmen. The idea was, as far as possible, to operate the workshop with automatic machines. Instead of animal or human muscle power the machines should be driven by the ever flowing, relentless hydropower – as Polhem said, a work force that needs neither food nor hay. Polhem was also engaged by the Swedish king Charles XII for other projects in the country: the construction of a dock at the naval shipyard in Karlskrona, the making of sluices in the Göta River near Trollhättan, and the invention of war machines for the Swedish army.

When Polhem was not busy with building models, constructing and maintaining the machines, he pondered over the nature of the world. As a natural philosopher and mechanics, he viewed the world as one giant machine. Everything is mechanical. The human body, the physical and geological processes and the starry sky followed mechanical principles, and according to Polhem, even the soul and the mind could be explained as simple mechanics. There is no difference between the artificial mechanics of the engineer and the natural mechanics of God's creation.[5] The natural

[5] Dunér 2013a.

machines, as well as those invented by man, were subjects to the same mechanical laws. Again and again he returned to this idea. Another recurring idea concerned the relationship between theory and practice, linked to the "Archimedean tradition" of the unity of theory and practice, and the mutual interrelations of science, technology, and mathematics, that to a great extent became important in the scientific revolution, for example in the use of mathematical proofs of mechanical theories, and not least for Simon Stevin's practical application of mathematics and physics.[6] The Archimedean ideal also infused military practice with rigorous mechanistic reasoning.[7] According to Polhem, theory without practical knowledge, and craftsmanship without theoretical insight, could not lead to any significant benefit for mankind. Mathematics and crafts should rather be combined. Among his countless drafts, fragments and notes there is an undated dialogue between lady Theoria and the master builder Practicus.[8] The young lady explains to the builder how mathematical knowledge can be applied to the construction of water mills. Practicus later explains his love to Theoria. The moral is that they would get extraordinary beautiful children if they entered marriage. The dialogue reflects – besides the evident gender denotation of theory and practice, as feminine respectively masculine – the social divide of theory and practice, the noble theoretical studies versus the ignoble practical labour. Theory and mathematics had higher status, while the practical life belonged to lower ranked carpenters and peasants. The dialogue also reflects Polhem's indeterminate social position; he is both an uneducated carpenter and a booklearned mathematician – or neither of them per definition. As such the fusion of theory and practice, the Archimedean polymathy, could be seen as a strategy to achieve higher social status, a social climbing from being an unlearned peasant, to transcend the class of carpenters, to reach the elite of the society. In the same time the craftsman-mathematician marketing the practical utility of learned, theoretical education, and how it could generate wealth and progress.

In 1697 Polhem founded a "Laboratorium mechanicum." The purpose was to develop mechanics, both theoretically and practically. The most advanced experimental machine developed within the framework of the laboratory was a hydrodynamic machine from 1702 that tested waterwheels of different types (Figure 2). A key element in his education of young technicians was his "mechanical alphabet" which consisted of simple, pedagogical wooden models that showed the basic mechanical laws.[9]

---

[6] Kemp 1986; Koetsier 2010; On the cognitive foundations of the scientific revolution, see Dunér 2016.

[7] Steele & Dorland 2005, p. 3.

[8] Polhem 1947, pp. 277–307.

[9] Dunér 2013c, pp. 59–62.

During the years he had a number of disciples and assistants in his mechanical laboratory and for his work assignments, among the more notable are Göran Vallerius, Emanuel Swedenborg[10], Augustin Ehrensvärd, and Carl Johan Cronstedt. His last undertaking was the construction of a new lock in Stockholm. At the time of his death in August 31, 1751, he was a celebrated man: member of the nobility, Knight of the Polar Star, fellow of the Royal Swedish Academy of Sciences, and known among his compatriots as the Swedish Archimedes or the Daedalus of the North.

Mechanical Education

In the seventeenth century, many foreign professionals, German craftsmen, Dutch merchants and Walloon smiths, were recruited and attracted to the economically growing but sparsely populated Sweden, to fill the needs of the expanding military power in northern Europe and its growing interest in cultural, scientific and technological development. Sweden had an expansionary policy and needed skilled people and capital in order to strengthen the economy of the country. New manufactories were established, waterpower was utilised, the iron industry got a boost, ports were re-equipped, natural resources as far north as to northern Lapland were investigated and mapped, and new forms of capital accumulation and work organisation came into use. All this was connected to the war and foreign policy. Sweden had been at war for decades, vast territories have been conquered, but economically the country was relatively defective as just a commodity producer of iron, copper, tar, and pitch.

Polhem's father, Wulf Christopher Polhammar, originally from Swedish Pomerania, was a merchant in Visby on the island of Gotland. He died in 1669, and Polhem's mother remarried a building contractor, who did not want to – as Polhem wrote later in his life – pay for his stepson's education.[11] Instead he was taken care of by his uncle in Stockholm. He moved to Stockholm in the autumn of 1671, and began studying at the German school. But just after two years also his uncle died. Polhem was now alone and must take care of himself. He managed to get positions at different estates around Stockholm. He set up a carpentry workshop with lathe and forge, where he could hammer, file, lathe, forge, fabricate and repair tools, knives and scissors. In his spare time, he made clocks and other more complicated mechanical devices.

The desire for mathematical and mechanical studies was so great that I could hardly sleep at night, Polhem stated later in his life when he thought

[10] Dunér 2013b.
[11] Polhem 1954, p. 396.

back to his poor youth.[12] He harboured dreams of getting the opportunity to study. The short time in primary school in Visby and Stockholm had left him with major flaws. But he came increasingly to realise that there was something in these books that he very much needed: knowledge. In order to develop his interest in mechanics and engineering, he came to understand that he needed theoretical knowledge that could fertilise his practical mechanical skills. One day surveyors came to the estate and transferred the meadows and arable lands to geometry on two-dimensional paper sheets. With amazement he followed their work to learn their art. He wanted to learn more about the art of surveying, so he took his savings and bought both a German and a Swedish textbook on surveying. The curious Polhem found, however, that there was a major obstacle for him in order to move on in his theoretical studies. He could not read Latin. All these amazing works in physics, mathematics and mechanics were written in a language he did not understand. But the priests master this language, he knew. The parish minister lent him a Swedish-Latin dictionary, and Polhem began to learn it by heart, but he soon realised that this method did not work. Another priest, Lars Olofsson Weldt, later came to his workshop for ordering a clock. Polhem saw now an opportunity. Through a deal with the priest, he paid his Latin lessons by making a clock showing hours, days, dates, new and full moon. Once a month, when Weldt came to Vansta estate where Polhem was employed, he got instructions and new homework to do.

But to develop his skills in mechanics even further Polhem needed theoretical university studies. His talent for mechanics was recognised by the parish minister, the learned Erland Dryselius, and thanks to a letter of recommendation, Polhem enrolled at Uppsala University in the autumn of 1687, not yet 26 years old. On the way to Uppsala he visited the surveyor office in Stockholm with the intent to become surveyor apprentice. While he was standing in the hall waiting to be called up, he read through the entry requirements for those who wanted to be accepted as surveying student. He understood that he would fail – he soon left the building, and continued to Uppsala. At the university in Uppsala he studied diligently, especially mathematics and physics. From astronomy professor Anders Spole's library, he borrowed books in mathematics and learned their contents by looking at the mathematical figures. He received a scholarship, but he also got a number of assignments in mechanics.

When Polhem studied in Uppsala one of the most divisive academic quarrels took place in the history of Uppsala University, the fierce debate between Aristotelians and Cartesians that raged during the years 1686–1689. The defenders of the Cartesian or mechanistic worldview regarded

[12] Polhem 1954, p. 390.

the world as one gigantic machine, a clock designed by the great watchmaker. Everything could be described in mechanical terms: planets, falling objects, plants, animals, and the human body. The task for the natural philosopher was just to find the true machinery behind the phenomena. This mechanical worldview suited Polhem the mechanic very well, and became his philosophy. The modern science that now emerged in Uppsala had as such an empirical vein, a belief in experiential knowledge and experiment. The professor of medicine, Andreas Drossander, introduced experimental physics and offered private lectures in which Polhem participated, where he made experiments with air pumps, microscopes, siphons, and magnets. Polhem might also have followed Johan Bilberg's lectures in modern mathematics. He probably got his basic knowledge of physics and astronomy from *Synopsis physica* (1678) by the medicine professor Petrus Hoffwenius, which was a widely used textbook in Uppsala. From the official lectures at the university he could gain much of the theoretical explanations of the mechanical worldview. For the practical knowledge of how to construct useful machines, he had to follow the private lectures that the professors occasionally offered besides the ordinary curriculum. Another professor of medicine, Olaus Rudbeck, taught in eight different technical subjects, in surveying, waterworks, artillery, fortification, house building, mechanics, sundials, and geography. In addition, he seems to have given classes in shipbuilding, agriculture, forestry, in building locks and mills, and the production of iron and copper as well as gardening. During Polhem's first year, Rudbeck had a class in building locks and canals. Polhem visited probably on numerous occasions the "mechanical house" and the experimental locks that Rudbeck had built.[13] Polhem's later constructions on canals, locks, docks, and mining machines show that Rudbeck's teaching likely had a significant impact.

It was a hard-working and diligent period these three years at Uppsala University. Polhem tells that he rarely slept more than three hours a night. It was of course difficult in the beginning, but after a while, he said, I felt much more cheerful and became quicker to understand and learn everything. And he explained: the brain becomes spoiled and inefficient by too much sleep. Sleepless nights with theoretical studies, perhaps, but it was probably practical mechanics, which occupied most of Polhem's time in Uppsala. Fellow students taunted him and called him "Spole's Smith." But the achievement that attracted most attention during Polhem's stay in Uppsala was his repair of the astronomical clock in Uppsala Cathedral, about which he said had "promoted all my luck in the world."[14] The

[13] Dahl 1995, p. 289; Eriksson 1994.
[14] Polhem 1729, p. 5.

cathedral clock had originally been constructed around 1504–1506 by a German monk in Vadstena, Petrus Astronomus.[15] Clockwork mechanics improved during the seventeenth century thanks to the pendulum clock, and became the cutting-edge technology of Polhem's time. Polhem took the cathedral clock apart, examined its different parts and operating mechanisms in order to find out how it was supposed to work. He learned new technology, and previous solutions, through imitation, copying, and reconstruction. It took him two years to get the clock running again. After a number of major changes of the mechanics, the repairing of the clock was completed in 1690.

The same year Polhem built another technically advanced clock, an astronomical clock that showed sunrise and sunset during a whole year, as well as the phases of the moon. It was among the first pendulum clocks ever constructed in Sweden. The original inventor of the pendulum clock, Polhem knew, was the Dutch physicist and astronomer Christiaan Huygens.[16] Huygens constructed a pendulum clock in 1656, described in his *Horologium oscillatorium* (1673), a work that Polhem may have studied. Two important regulatory mechanisms in clock making, which Polhem made use of, were invented by Huygens: the pendulum and the spring mechanism. With a pendulum, time could simply be divided into equal-sized units. Polhem was, most likely, the only one in Sweden at that time who could build a pendulum clock after Huygens's construction.

The main source concerning Polhem's early education is his own autobiographies, which were written much later as a member of the Royal Swedish Academy of Sciences.[17] When he tells his life story, he not only tells it for others, he also tells the story – and constructed it – for himself. Autobiography, this noble form of art and main expression of human self-deception is largely a matter of who one wants to be in front of one's own eyes and those of others. The autobiography does not perhaps reveal so much about who the person behind it really is, or what that person has actually achieved, not perhaps even his self-perception, but rather about what the autobiographer wants the world to observe and recognise. It is about self-fashioning. In his autobiographies Polhem wants to create an image of himself as the poor orphan, who with ingenuity, talent, and diligence alone, worked hard on his own in a grudging and hostile environment. It is also this image that has repeatedly been retold to posterity in the literature on Polhem. Polhem's autobiographic self-fashioning makes him also to become a polymath, that boasts his polymath range of skills and

[15] Pipping 1992, p. 156.
[16] Andriesse 2005.
[17] Polhem 1954, pp. 387–399.

knowledge. He is not just a craftsman or carpenter, but a mathematician, an Archimedean polymath.

Another recurring theme in the history of ingenuity is that geniuses never have any teachers, they teach themselves directly from nature. Polhem is commonly described as self-taught, unprecedented, and independent of the knowledge of others. If one does not immediately accept Polhem's self-construction as a solitary genius, one needs to find other sources from his time that say something about how he was regarded by others, who he met, with whom he collaborated, and how the society around him looked like. A distinct trait in Polhem's career from school boy to famous mechanicus is – contrary to the story of a solitary self-made genius – his dependence on others, other people's contacts, power, money, and knowledge. This is, what could be called his network, a fixed regulated system of patrons and clients. To be able to make a career one needs someone who opens the doors and writes recommendation letters. Polhem had his Weldt, Dryselius, Spole, and Rudbeck, who not only opened his eyes for new knowledge, but also opened new career paths for him.

Mechanical Perception

Polhem said that he could, by just seeing a machine only once in motion, no matter how complicated it was, build a new one with all the construction details. There were no inventions, he said, which he would not immediately know whether they were possible to execute or not.[18] The mathematician Samuel Klingenstierna, who held a memorial speech about Polhem at the Royal Swedish Academy of Sciences in 1753, was very impressed by how Polhem could bring home to Sweden so many new machines.[19] He had a wonderful ability to conceptualise mechanics. It is remarkable, Klingenstierna exclaimed, that he never used drawings or descriptions, but maintained an abundance of highly complex machines in his memory. Polhem seemed to have a phenomenal technical, spatial thinking, an eye for mechanics, motions, and transmissions. The practical experience of the Archimedean polymath rested on visual and spatial cognition.

To understand how a clock works one has to take it apart – as Polhem did – and rebuild it. Polhem learned technology in this way by seeing and by doing with his own hands in an encounter with the objects around him. Polhem as constructor of mechanical devices imagined technology in mental visions, both as inner, mental models or representations, and in external representations, as physical models made by iron and wood. To some extent, technical talent seems to do with how a person manages to

[18] Polhem 1729, p. 76.
[19] Klingenstierna 1753.

create internal, but also external representations of mechanical relations in the outside world. The speculative mind of a mechanicus, Polhem claimed, includes "an astute reflection and good memory that retains the whole structure of the machines in the head until everything is completed."[20] The concrete external models were not only tools to think with, but can be seen as an integral part of technological thinking. Models play a number of different roles in technological change. The use of physical, scale models had educational purposes. Wooden and clay models had already been utilised as teaching aids by Italian engineers and by Stevin in the Netherlands.[21] Polhem himself had a mechanical laboratory and mechanical alphabet, which visualised mechanics and technical ideas in order to understand how machines function and how to build them in full scale. Models could be used for experimental purposes, through parameter variations testing different technological solutions, such in the case of Polhem's hydrodynamic experimental machine. In the case of Polhem's model chamber, three-dimensional models in smaller scale could be used instead of two-dimensional drawings. Models could also be connected to economic interests and motivations, as a kind of advertising or product presentation; or simply as pleasurement and entertainment, as magnificent pieces of technological wonder. But the key element here is that models are an externalisation of thought, that the inventor thinks with moving objects outside the brain and body.

Important for Polhem's technological advancement was when he and his friend Samuel Buschenfelt in January 1694 got a scholarship by the Royal Board of Mines to undertake a trip to continental Europe and England. It was intended as an educational journey for two promising mechanics to develop their technological skills and to learn more about the latest technology. But it also had political, economic motives: new and valuable technology could be brought to Sweden. Polhem's receptive mind was valuable at a time when export bans and tariffs made it difficult to bring original machines and models from England and other countries to Sweden. By seeing the machines in place and in operation, he could reconstruct and make copies of them. They were, one might say, "industrial spies" sent out on behalf of the Swedish Crown to collect knowledge of new technologies, innovations and new manufacturing methods for the benefit of the nation. They studied various industries and mechanical installations, took notes of new inventions, manufactures and met learned men, technicians, and scientists. To a great extent innovations and technological change depend on carriers of new technologies, as in the case of Polhem and Buschenfelt,

[20] Polhem 1729, p. 14.
[21] Krüger 2015.

that skilled craftsmen travel to another country or were sent out on educational journeys, and brought back home new ideas and technical solutions.

Technological change was partly a result of a spatial transfer of technological knowledge. More important were probably the small improvements step-by-step, day-by-day, that rested on acquired experiences. Radical transformation and revolutionary innovations were rare. Technological change, inventions and innovations, can be considered as processes where one has identified or experienced a problem that needed a solution. But it could also be processes when one recognises a possibility to do something that previously has been regarded as impossible or was not perceived at all, as something far beyond the horizon of human thinking and necessities of life. As such, Polhem's trip through Europe was a journey of opportunities, a way of seeing possible solutions to known and unknown problems. His travel, which lasted between 1694 and 1696, became of great importance for his technological work. Many of the technological solutions, machines and other things that he saw during the trip later reappeared in his own technological projects. Right after this trip, he started a couple of projects that came to have great significance for the technological and proto-industrial change in eighteenth-century Sweden.

Polhem and Buschenfelt travelled through Bremen to the Netherlands, passed Deventer and Amersfoort, and arrived to Amsterdam on December 4, 1694. The Netherlands was known to them as a country with advanced technology and well developed commerce, trade, and manufacturing industry. Buschenfelt wrote that during the summer Holland looked like a pleasurable garden, with beautiful alleys, parterres and canals, with many hundreds of manufactures, machines, and buildings everywhere. For good reasons the entire country could be called an "officina machinarum."[22] During their stay in Holland they spent most of their time in the university towns of Utrecht and Leiden, and in The Hague. They observed canals, wind mills for grinding grain, sawing boards, making paper, and cutting tobacco, but they also visited a silk factory in Utrecht, a limekiln, and a brick factory. Buschenfelt noted that the windmill near de Heere Port in Leiden had nine floors, was 88 feet high, with a diameter of 26 feet at the base and 16 feet at the top.

In Scheveningen, they saw an unusual machine – a sailing chariot.[23] These, Buschenfelt says, had been sailing on the smooth sandy beach along the coast of Holland. A distance of 70 kilometres took two hours with a

[22] Buschenfelt, KB, p. 7.
[23] Buschenfelt, UUB, p. 46; See also Happel 1687, p. 566; Dijksterhuis 1970, pp. 104 f.; Devreese & Vanden Berghe 2008, pp. 45 f.

flying wagon loaded with 26 distinguished people. The wagon, Buschenfelt tells us, had been built at the expense of the Prince of Orange, Maurits of Nassau, and was invented by the mathematician Simon Stevin. But due to its age, it was discarded and dismantled when Polhem and Buschenfelt visited Scheveningen. Instead a smaller one had been made in its place, Buschenfelt says, with which the King of England had sailed "when I was in The Haag."[24] At the rear, there was a steering rod connected to the wheels, so it could be manoeuvred like a sailing boat.

During the time in Leiden, they learned to grind lenses for microscopes, tubes and telescopes, both concave and convex lenses. In such a lens, Buschenfelt tells, I saw an object 18 times longer and wider than it is in reality.[25] With these lenses, one could see things many hundreds or thousands times larger, one could clearly see the globe-shaped bodies in the blood, the circulation of the blood in eels and other transparent fishes and insects, and worms in vinegar and other unfamiliar things in nature. They learned about light refraction of different lenses, if they are suitable for tubes, and how to assemble tubes with three or four lenses. They witnessed demonstrations by the physicist Burcher de Volder in Leiden and met the old Christiaan Huygens. Besides studying Antonie van Leeuwenhoek's microscope, they examined Samuel van Musschenbroek's instruments for experiments in physics. All these instruments they saw enhanced the human capacities, strengthened the inborn perception, let them see further into matter and further out in the heavens, as such they extended the human mind.

The only source to Polhem and Buschenfelt's travel is the latter's travel notes.[26] Polhem himself did not write any travel journal, but after returning home, he sent on October 26, 1696, a brief travel report to the board of mines.[27] He says that he had tried to do his very best in obtaining knowledge about mechanics. He had made careful observations and memorised all sorts of works and machines that he saw during the journey through Holland, England, Brabant, France, Germany and Denmark, such as waterworks, manufactures, saw mills, oil mills, paper mills, mills for cement, colours, and plaster, grinding and polishing mills, hammer works, and forges. Windmills for flour, tobacco, mustard, etc., finer sawmills, thimble making, brick and lime factories, silk weaving, looms for fabric, velvet, ribbons, laces, socks, etc., and also flatboats, sluices, drawbridges, dams, pilings, dredgers, cranes, glass and mirror factories, astronomical clocks, carillons, mathematical, astronomical and physical instruments, and

[24] Buschenfelt, KB, pp. 67 f.
[25] Buschenfelt, KB, p. 78.
[26] Buschenfelt, KB; Buschenfelt, UUB.
[27] Polhem, KB, X 265:1.

other artful things in curiosity cabinets “that I do not have time to mention.” All these machines, he says, he could reconstruct, if it is required. He had carefully examined all these machines with his own eyes, but he never made any notes during the travel, nor any drawings of the machines, or in other words, he did not use any external memorizing techniques. Everything was stored in his memory. To begin with, of course, one could question Polhem’s self-rendering. The report had an obvious rhetoric intention to show that he had used the travel grants wisely and efficiently and that he now could offer his ingenuity and highly improved technical proficiency to the Swedish state. But nevertheless, the passage indicates a certain memory for mechanical connections, partly due to the unambiguous logic of mechanics, his experience of mechanical causalities, and a clear awareness of the objectives. A process based on an unequivocal causality with a limited number of alternatives is easier to remember than a process of inconsequent occurrences with an indefinite number of alternatives.

Polhem constructed machines in his head. He had, like many other mechanics, a spatial ability by which he could join together mechanical parts to form complex machines. He could see if a machine worked or not by trying it in his head. No words were needed, just inner images, where one mechanical part was put together with another in the imagination, in mental representations and models of reality. Imagination, the ability to visualise existent or non-existent things and events in the head, is an efficient way of anticipate the future. One does not need to perform time-consuming trials and experiments in the physical world. Everything could be perceived with the inner eye. Technology rests partly on a non-verbal thinking. The movements of the models could be kept in memory and later be constructed in larger scale. Mechanical, technological imagination is a spatial thinking of objects in motion in three dimensions, not a two-dimensional representation, nor a linguistic thinking in words and characters. When Polhem tried to describe his inventions, language was not sufficient. Just after some few lines, he surrenders. How the machine works is not possible to describe, he admitted, it must be seen in action in order to be understood and comprehended.

Polhem observed and examined new technology with his own eyes in workshops, mines, factories, mills, canals, in towns and rural areas, as models in university collections and curiosity cabinets. He registered technology around him in the physical world, in farm kitchen as well as in palace gardens. The journey through European workshops and manufactories was a trip through the advances of technology. To a lesser extent, his technological knowledge was a result of reading and theoretical studies. In some few cases, one can make assumptions about what books he browsed and might have read. He bought a copy of *Recueil de diverses pieces touchant quelques nouvelles machines* (1695) by the French physicist Denis Papin.[28] He glanced through books in technology with illustrations of fantastic machines, such as Johann Christoph Sturm's *Collegium experimentale* (1676–1685), which describes diving bells, air pumps, siphons, tubes, the Magdeburg hemispheres, the mechanics of muscles and other marvellous machines. A genre of books called "Theatrum machinarum" by for example Jacques Besson and Vittorio Zonca, excelled in the most strange and imaginative, but not seldom futile machines.[29] Polhem studied the largest technical reference book of the time, *Theatrum machinarum* (1724–1739) by the German experimental physicist and instrument maker Jacob Leupold.[30] It could be said, that the illustrated books in technology were rather meant for the communication between engineers, investors and scholars, than between them that could build the machines, engineers and craftsmen. The costly copper-plate illustrated books in mechanics, Polhem said, that have drawings of numerous inventions – one more remarkable than the other – serves only to make ignorant people to become astonished.[31] In a German edition of Agostino Ramelli's work on the art of mechanics, *Schatzkammer, Mechanischer Künste* (1620), owned by the eighteenth-century Swedish instrument maker, Daniel Ekström, Polhem's assessment of Ramelli is noted: most of the depicted machines were not practicable.[32]

The few works that Polhem published during his lifetime contains almost no illustrations at all, partly due to the lack of skilled engravers and partly because of Polhem's thriftiness. His most important published work, *Kort berättelse om de förnämsta mechaniska inventioner* (1729), contains only one simple illustration (Figure 3). The full title in translation would be: "Short account on the chief mechanical inventions that time after time have been invented by the councillor of commerce Christopher Polhem and executed for the benefit and service of the public, and about the fate that some of them have had through the unfavourable changes of time." As the long title reveals, its purpose was rather to show his own genius, that he had an ingenuity that had not received its fair acclamation. However, there exist lots of drawings by his disciples, beautiful sketches in ink, wash drawings, and watercolours (Figure 4). Some of the best were made by the students Ehrensvärd and Cronstedt who stayed at Polhem's manufacturing works the summer of 1729 to learn the art of mechanics. The illustrations depict

[28] Papin 1695; Liljencrantz 1939, pp. 300 f., n. 7.
[29] Besson 1578; Zonca 1607.
[30] Leupold 1724–1739.
[31] Polhem 1947, p. 364.
[32] Ramelli 1620, in Stockholm University Library; Amelin 1999, pp. 101 f.

machines that they actually saw at Stjärnsund or in Falun mine, in Stockholm and elsewhere, which they had examined in order to acquire knowledge of Polhem's technological innovations. Making illustrations was a pedagogical exercise for enhancing visual thinking in technology. The visualisation of mechanics was one of the major ingredients of Polhem's pedagogy, to see mechanics in action with one's own eyes, to make sketches, and above all, see, touch, and construct models. Another important pedagogical presumption was the unity of theory and practice, that the both practical and theoretical education should be performed in Swedish, including a deconstruction of machines into smaller simple parts.

The images have, however, a kind of uncertainty with them, which makes them often problematic as historical sources. Do the pictures correspond to existing technology, planned, intended technology, or just imagined technology? Polhem himself never made any detailed plans or drawings of his machines. But there exist simple sketches in his manuscripts that visualise mechanics, the inner structure of matter and other phenomena beyond the limits of vision (Figure 5). There is no evidence that he ever used design drawings. What he instead utilised were wooden models. Drawings might be good in general terms, he says, but in order to be accurate and precise, models are more useful, especially if one wants to build complicated machines, but lacks greater experience.[33] Technology could be comprehended more easily through models. With models one could also diffuse new technologies. Despite the lack of precise drawings and illustrations he thought visually, but not in two-dimensional, static images on a flat surface, but in three dimensions in motion, in models that one could touch, walk around, and see in action.

Polhem's technological thinking was a spatial, non-verbal thinking. His technical solutions and scientific ideas existed first as inner visions without words. Then he tried to translate his mental image into words or to transfer the internal image to a drawing on a paper or to a scale model in order to excite similar mental images in the mind of another person who finally constructs the mechanical idea in full scale in three dimensions.[34] Polhem's Archimedean polymathy, that put equal emphasis on practical experience, rested on visual thinking, to visually and spatially experience technology in action.

Mechanical Communication

Communication and language, the problem of transferring ideas about technology and science, was in the centre of Polhem's technological

---

[33] Polhem 1947, p. 40.
[34] Cf. Ferguson 1977, p. 828.

pedagogy. He returned many times to the idea of a "universal language," a perfect language that can be spoken and understood by everybody irrespective of education or origin.[35] His preoccupation with a universal language had probably partly to do with his own faltering educational history, his own difficulties in reading books, understanding Latin and writing correctly. Despite these obstacles, they did not stop him from writing an immense amount of drafts on all kinds of topics, from technology and physics to economics, pedagogics, and philosophy of language. Polhem took his starting point in the contemporary interest in the universally valid, the unambiguous, in logic, in order and classification.[36] Fundamental problems at this time concerned the logical method, the systematic classification of knowledge, and the construction of an encyclopaedia of knowledge.

In a way, it already existed a universal language: Latin. But it was not perfect. The artificial universal languages can be seen as attempts at breaking the dominance of Latin as the lingua franca, its socially exclusive character. Latin constituted a chasm that was difficult to bridge between elite culture and popular culture, and locked out women, craftsmen, farmers, and a smith and carpenter like Polhem. His own lack of proficiency in Latin was a clear mark of not fully be included in the learned category. Polhem was not a polyhistor in the sense as someone who seeks both eloquence and erudition. Classical rhetoric eloquence and humanistic learning were not ingredients of Polhem's Archimedean polymathy. He also often criticised Latin as an obstacle for thinking and the improvement of the sciences. In this respect he reminds of Stevin, who advocated the use of Dutch in science, partly in order to make scientific works practically useful for the common people. For that purpose, he introduced new technical words in vernacular. Those who lacked a scholarly education would otherwise, Stevin feared, be forever excluded from scientific activity.[37] For Stevin, language was a key to scientific achievements, and he, like Polhem, stressed the importance of vernacular learning. Learning science in one's mother tongue saves both time and effort. Latin should not be a barrier, Stevin maintained.[38] Also for Polhem, Latin studies rhymed badly with his cult of utility, and his eagerness to disseminate new findings and inventions to the broader population. Much because of his own wavering educational path, he had great concern for the teaching of young people. Learning Latin or other subjects by reeling off texts by heart was not worth much. It was, Polhem asserted, like giving a book to someone who could not read, or spectacles to

[35] Dunér 2013c; cf. Yates 1966; Eco 1995; Rossi 2000.
[36] Dunér 2019.
[37] Stevin 1955, p. 7; On language, see also Dijksterhuis 1970, pp. 126–129.
[38] Wal 1993, p. 155.

a blind person.[39] Instead he advocated teaching in Swedish with Swedish books and with practical exercises. He did not advocate Swedish as a language for science teaching because of some linguistic superiority for expressing things and ideas, such as in the case of Stevin's view of Dutch as the ideal language and key to reality. For Polhem the simple reason was just that it was the mother tongue of his young apprentices. It had pedagogical advantages for enhancing the understanding. To this was added a modern educational ideal. It was not the classical, traditional wisdom found in books written by the wise men of antiquity in which he found meaning. Polhem does not represent book learning, but a particularly empirical knowledge appropriated through the senses and with the hands.

Polhem himself never really managed to learn Latin. There is not one single manuscript in Latin in Polhem's writing. From what could be concluded based on preserved documents it seems that Polhem was not a keen reader of books; there are few concrete references or comments to important passages in other books. His manuscripts show an irregular and erratic spelling (more than what one would expect), and inverted word sequence, that might suggest dyslexia. The deficiency of Latin, the cumbersome learning, and his own shortcomings in reading and writing, led him into the endeavour to invent his own language. His first drafts of a universal language were made at a time characterised by a general interest in linguistics and philosophy of language, in national languages and their sounds and grammar, in the connections between words and objects, the character and the characterised. The artificial languages of the seventeenth and eighteenth centuries reflect also a striving towards the cosmopolitan, to construct a language that could be learned irrespectively whom you are, from where you come or what mother tongue you have.

Linguistically, both semantically and phonetically, Polhem's universal language emphasises a number of advantages. The envisioned universal language should be pedagogic, more efficient and concise than the ordinary natural languages, more regular and based on a firm logical foundation. The undated manuscript "Nomina rerum naturalium per philosophiam novam," which despite its title is written in Swedish, provides a fairly good picture of how such a universal language could look like.[40] Notable are the speech sounds, vowels and consonants, followed by grammar, syntax, phonology, and lexicon. Like other proposed universal languages, great emphasis is placed on nouns, thereafter verbs, after which adjectives are added. The senses and the elements play a central role in Polhem's universal language (Figure 6).

---

[39] Bring 1963, p. 83.
[40] Polhem 1954, pp. 333–338.

The desire to learn different things in natural sciences tempts many to start reading books, Polhem explains. But the difficulties soon make us tire, so that we often stop half way. This is because we have to eye through an innumerable amount of letters and words that are irrelevant, and which merely tire the eyes and the brain and put a strain on health. Instead, he speculates, we could invent a new way of writing books, where words and sentences were concentrated, so that an entire book could be summarised on a sheet or two "because then a large book would not so easily frighten many from reading it, as now usually happens, and then people would gain knowledge quicker than otherwise. This I have thought about for a long time," Polhem says, but it has always proved to be difficult and tiring, particularly when other duties and problems have interrupted my studies. But I still consider this "as a thing that would be no less useful and desirable than finding perpetuum mobile and lapis philosophorum which surely are impossible in themselves, but none the less has led many to spend both time and welfare upon." Many learned men have "put their brains to work thereon, but like me, have stopped half way." But like all gold-makers who have lived and died with the idea that it should be possible some time in the future, "therefore I also do the same."

Behind this search for a universal language is the supposed isomorphism of words and things, between expression and content, and the treatment of language and the world as a kind of combinatorics. Something in this way, one finds in the linguistic ideas of Stevin, concerning monosyllables and compounds, representing non-complex respectively complex things.[41] According to Stevin language could be compared with geometry, where one builds up something from the smallest elements to the more complex. Polhem's thinks very much in the same way as Stevin. The idea of the universal language, Polhem's or others, can be seen as a kind of "atomisation" of reality that rests on the human ability and obsession for categorisation and classification of things and phenomena in the human lifeworld. In the mechanistic worldview, everything seems to consist of building blocks; mechanical parts that were put together into a world machine. Thoughts consist of simple ideas, words of letters, music of notes, and nature of numbers. Machines and mechanical movements also have their own, simple parts. Polhem's teaching in technology included "the mechanical alphabet," which consisted of a large number of simple, educational wooden models showing the fundamental laws of mechanics (Figure 7).[42] The models represented the simple and indivisible elements of mechanics, quite simply the building blocks of all engineering, such as the

[41] Wal 1993, p. 152.
[42] Polhem 1729, pp. 75–77.

steel spring, the cogwheel, the ratchet wheel mechanism, the windlass or other mechanical elements that each represented a "letter" in the mechanical alphabet. They described different types of mechanical movements, such as the transfer of one type of movement into another, from rotating into straight movement, and other rotating and forwards-backwards movements. Polhem's mechanical alphabet became a pedagogic system, easy to learn, to observe with one's eyes and to try and feel with one's hands.

With knowledge about these mechanical letters, a mechanic could build any machine he wished. Just like a poet, Polhem declares, can write the most beautiful poetry with the help of the ordinary alphabet, an engineer could learn the mechanical alphabet and form "sentences" of the mechanical letters, that is to say construct complicated machines that could carry out useful work. The machines became like words and sentences. It was just as important, Polhem claimed, for a mechanic to know all the cogs, levers and catches in a machine as it was for a person of book learning to know the letters of the alphabet and the meaning of words.[43] There were some particularly important mechanical letters that corresponded to the vowels in the ordinary spoken language. In the same way as we could not write words without vowels, it was also not possible to build a machine without any of the five mechanical vowels, namely the lever, the wheel, the screw, the block, and the wedge. The most important was the lever. Cogwheels, chains, bearings, joints and springs were probably to be regarded as consonants, not as necessary to be included in each machine.

The crucial task was to learn the right way of writing. With a mechanical alphabet, one could find many new, functioning inventions. Polhem's mechanical alphabet was based on the idea of the world as a construction kit, like a character system with an infinite number of possibilities for different combinations. The world consisted of small parts that could be put together into units, small atoms, corpuscles that formed bodies and objects, of consonants and vowels that formed words and sentences, of digits and numbers, simple geometric figures that described the motions of the Universe, of small mechanical letters that formed mechanical words and books. Polhem's mechanical alphabet became a world-renowned attraction. The German technologist Johann Beckmann saw this ABC in 1766, as did the future Venezuelan freedom hero Francisco de Miranda during his visit to Stockholm in 1787.[44]

Conclusion

Many factors affected the formation of a polymath, of course, obvious

[43] Cronstedt, TM, p. 2.
[44] Beckmann 1995, p. 131; Miranda 1929, pp. 40 f.

social, cultural, economic, and political factors. Polhem's entry to the scene occurred during a time when the Swedish state had an expansive mercantilistic manufacturing and trade policy. The need for enhancing the profitable mining industry and the protection of domestic proto-industry clearly favoured such entrepreneurs as Polhem. The craftsman-mathematician was to some extent an answer to the demand of skilled entrepreneurs in technology, someone who had both insight into the learned world of mathematics and the practical experience and reality of the manufacturing industry. However, there are peculiarities in Polhem's way of approaching technology, due to his faltering linguistic skills of Latin and of reading, partly compensated by an exquisite visual thinking in three dimensions. Also his indecisive social identity, between craftsman and nobleman, between illiterate and savant, gives a certain touch to his obsession with the unity of theory and practice. The practical-theoretical combination of polymathy, the craftsman-mathematician, is to some extent a self-fashioning to win commissions and transcend the social barriers between craftsmen and learned men. The Archimedean polymath tried to pull these seemingly, both socially and cognitively, incompatible ways of gaining knowledge together.

Fundamental for the formation of a polymath is learning from others, that is education, to observe, imitate, and copy behaviours, procedures, and views through instruction and adjustment. Polhem was dependent on others' instructions, knowledge, and experiences, and the cognitive and intellectual environment or context. He learned through observing and copying others, through seeing similarities, learning from previous experiences and solutions, followed by reconstruction and replication. In achieving this, the craftsman-mathematician needed a number of mental capacities. In this chapter, two have been highlighted: perception and communication. The Archimedean polymath, the craftsman-mathematician of Polhem's sort, needed the ability to visualise three-dimensional spaces in motion. Technological thinking is to a great extent a non-verbal thinking, a way of making visual representations of technology. In Polhem's case, we find mental, internal visualisation of technology. He seemed to have certain skills to keep complex mechanical movements in his head, to elaborate with inner representation of external objects. Even external representations of technology played an important role in his technological thinking, not so much in the form of two-dimensional drawings, rather as three-dimensional wooden models in motion. These models were a kind of externalisation of thought. Another crucial prerequisite for the formation of a polymath was communication, i.e., ways of sharing and transferring mental content from one mind to another. For Polhem language and communication of technological ideas played a central role in his technological pedagogy. He searched for a universal language, a more efficient, concise, and regularly way of obtaining information, storing and disseminating knowledge. His mechanical alphabet was a pedagogical tool for understanding the fundamental laws as well as finding the smallest components of mechanics of which one could construct complex machines.

A polymath is in this sense a thinking subject, such as Stevin or Polhem, who sees connections between seemingly compatible phenomena, who combines diverse areas of knowledge in order to come up with new ideas, new solutions, new explanations. Polymathy is a way of creative thinking.

Captions

1. Polhem's hoisting machine, Stora Kopparberg mine in Falun. Engraving made in Holland by Jan van Vianen after a drawing by Samuel Buschenfelt. Photo: Lund University Library.
2. The hydrodynamic experimental machine from 1702. Sketch by Göran Vallerius, 1705. Photo: Royal Institute of Technology, Stockholm.
3. The geometry of mechanics, in Polhem's *Kort berättelse om de förnämsta mechaniska inventioner* (1729). Photo: author.
4. Carl Johan Cronstedt's ichnography of the iron forge, Stjärnsund 1729, with ovens, hammers, bellows, and water wheels. Photo: Museum of Technology, Stockholm.
5. The mechanics of the inner structure of matter. Sketch by Polhem in *De gravitate et compres[s]ione aeris*. Photo: Royal Library, Stockholm.
6. Polhem's universal language, *Orda teckn på naturens materialer och dess egenskaper* (c. 1710–1711). Photo: Royal Library, Stockholm.
7. The mechanical alphabet. Sketch by Carl Johan Cronstedt, 1729. Photo: Museum of Technology, Stockholm.

References

Unpublished sources

Buschenfelt, Samuel, *Berättelse till Bergskollegium över hans resa till bergverken i Tyskland, Holland, England, Frankrike och Österrike 1694–1696 med tillhörande ritningar*, Royal Library, Stockholm (KB), L 70:54:1.

Buschenfelt, Samuel, *Reseanteckningar 1694–1697*, Uppsala University Library, Uppsala (UUB), X 366.

Cronstedt, Carl Johan, *Machiner, som till största dehlen äro uti wärket stelte [av Polhem] och af Ehrensverd och mig afritade åhr 1729: tillika med andra tilökningar som iag sielf giort tid effter annan*, Swedish National Museum of Science and Technology, Stockholm (TM), 7405.

Polhem, Christopher, *Afskrift af Chr. Polhammars bref 1696 till Bergs Collegium ang.*

hans utländska resa och förslag till inrättandet af ett mekaniskt laboratorium, Royal Library, Stockholm (KB), X 265:1.

Published sources

Amelin, Olov. 1999. *Medaljens baksida: Instrumentmakaren Daniel Ekström och hans efterföljare i 1700-talets Sverige*. Uppsala: Institutionen för idé- och lärdomshistoria.

Andriesse, Cornelis Dirk. 2005. *Huygens: The Man behind the Principle*, transl. Sally Miedema. Cambridge: Cambridge University Press.

Beckmann, Johann. 1995. *Schwedische Reise nach dem Tagebuch der Jahre 1765–1766*. Lengwil: Libelle.

Besson, Jacques. 1578. *Theatrvm instrvmentorvm et machinarum Iacobi Bessoni Delphinatis, mathematici ingeniosissimi. Cum Franc. Beroaldi figurarum declaratione demonstratiua*. Leiden: Barth. Vincentium.

Bring, Samuel E. 1963. A Contribution to the Biography of Christopher Polhem. In *Christopher Polhem: The Father of Swedish Technology*, transl. William A. Johnson, 3–105. Hartford CT: American Swedish History Museum.

Dahl, Per. 1995. *Svensk ingenjörskonst under stormaktstiden: Olof Rudbecks tekniska undervisning och praktiska verksamhet*. Uppsala: Institutionen för idé- och lärdomshistoria.

Devreese, Jozef T. & Guido Vanden Berghe. 2008. *"Magic is No Magic": The Wonderful World of Simon Stevin*. Southampton: WIT.

Dijksterhuis, Eduard Jan. 1970. *Simon Stevin: Science in the Netherlands around 1600*. The Hague: Martinus Nijhoff.

Dunér, David. 2010. Daedalus of the North: Swedenborg's Mentor Christopher Polhem. *The New Philosophy* 113:3–4, 1077–1098.

Dunér, David. 2013a. Christopher Polhem's Experiments Concerning the Creation. In *The 18th Century and Europe*, ed. Elizarija Ruskova, 114–118. Sofia: Sv. Kliment Ohridski.

Dunér, David. 2013b. *The Natural Philosophy of Emanuel Swedenborg: A Study in the Conceptual Metaphors of the Mechanistic World-View*. Dordrecht: Springer.

Dunér, David. 2013c. The Language of Cosmos: The Cosmopolitan Endeavour of Universal Languages. In *Sweden in the Eighteenth-Century World: Provincial Cosmopolitans*, ed. Göran Rydén, 41–65. Farnham: Ashgate.

Dunér, David. 2016. Science: The Structure of Scientific Evolutions. In *Human Lifeworlds: The Cognitive Semiotics of Cultural Evolution*, eds. David Dunér & Göran Sonesson, 229–266. Pieterlen and Bern: Peter Lang.

Dunér, David. 2019. The Axiomatic-Deductive Ideal in Early Modern Thinking: A Cognitive History of Human Rationality. In *Cognitive History: An Introduction to a Historical Methodology*, eds. David Dunér & Christer Ahlberger, 99–126. Berlin: De Gruyter.

Eco, Umberto. 1997 [1995]. *The Search for the Perfect Language*. Oxford: Blackwell.

Eriksson, Gunnar. 1994. *The Atlantic Vision: Olaus Rudbeck and Baroque Science*. Canton

MA: Science History Publications.

Ferguson, Eugene S. 1977. The Mind's Eye: Nonverbal Thought in Technology. *Science* 197:4306, 827–836.

Happel, Eberhard Werner. 1687. *Gröste Denkwürdigkeiten der Welt oder so genannte Relationes Curiosae …*, III. Hamburg: Wiering.

Huygens, Christiaan. 1673. *Horologium oscillatorium, siue, De motu pendulorum ad horologia aptato demonstrationes geometricæ*. Paris: Muguet.

Kemp, Martin. 1986. Simon Stevin and Pieter Saenredam: A Study of Mathematics and Vision in Dutch Science and Art. *The Art Bulletin* 68:2, 237–252.

Klingenstierna, Samuel. 1753. *Åminnelse-tal öfver Kongl. Vetensk. academiens framledne ledamot, commerce-rådet och commendeuren af Kongl. Nordstjerne-orden, herr Christopher Polhem, på Kongl. Vetenskaps acad. vägnar hållit i Stora Riddarhus-salen, d. 25. junii, år 1753*. Stockholm: Salvius.

Koetsier, Teun. 2010. Simon Stevin and the Rise of Archimedean Mechanics in the Renaissance. In *The Genius of Archimedes: 23 Centuries of Influence on Mathematics, Science and Engineering*, eds. S. A. Paipetis & Marco Ceccarelli, 85–111. Dordrecht: Springer.

Krüger, Jenneke. 2015. A First Mathematics Curriculum: Stevin's Instruction for Engineers (1600). *International Journal for the History of Mathematics Education* 10:1, 79–88.

Leupold, Jacob. 1724–1739. *Theatrum machinarum…* Leipzig: Zunkel.

Liljencrantz, Axel. 1939. Polhem och grundandet av Sveriges första naturvetenskapliga samfund jämte andra anteckningar rörande Collegium Curiosorum. *Lychnos* 1939, 289–308.

Lindgren, Michael H. 2011. *Christopher Polhems testamente: Berättelsen om ingenjören, entreprenören och pedagogen som ville förändra Sverige*. Stockholm: Innovationshistoria förlag.

Lindroth, Sten. 1951. *Christopher Polhem och Stora Kopparberget: Ett bidrag till bergsmekanikens historia*. Uppsala: Almqvist & Wiksell.

Miranda, Francisco de. 1929. *Archivo del general Miranda* III. Caracas: Editorial Sur-America.

Papin, Denis. 1695. *Recueil de diverses pieces touchant quelques nouvelles machines*. Cassel: Jacob Estienne.

Pipping, Gunnar. 1992. Christopher Polhems astronomiska ur. *Dædalus* 1992, 156–163.

Polhem, Christopher. 1729. *Kort berättelse om de förnämsta mechaniska inventioner som tid efter annan af commercie-rådet Christopher Polhem blifwit påfundne och til publici goda nytta och tienst inrättade, sampt om det öde, som en del af dem hafft genom tidernas oblida förändringar.* Stockholm: Biörkman.

Polhem, Christopher. 1947. *Christopher Polhems efterlämnade skrifter I. Teknologiska skrifter*, ed. Henrik Sandblad. Uppsala: Lychnos-bibliotek.

Polhem, Christopher. 1954. *Christopher Polhems efterlämnade skrifter IV. Varia*, ed. Bengt Löw. Uppsala: Lychnos-bibliotek.

Ramelli, Agostino. 1620. *Schatzkammer, mechanischer Künste,* ... Leipzig: Liger.
Rossi, Paolo. 2000. *Logic and the Art of Memory: The Quest for a Universal Language*. Chicago IL: University of Chicago Press.
Steele, Brett D. & Tamera Dorland, eds. 2005. *The Heirs of Archimedes: Science and the Art of War through the Age of Enlightenment*. Cambridge MA: MIT Press.
Stevin, Simon. 1955. *The Principle Works of Simon Stevin* I, ed. E. J. Dijksterhuis. Amsterdam: C. V. Swets & Zeitlinger.
Sturm, Johann Christoph. 1676–1685. *Collegium experimentale, …*. Nürnberg: Endter.
Wal, Marijke J. van der. 1993. Logic, Linguistics, and Simon Stevin in the Context of the 16th and 17th Centuries. In *History of linguistics 1993*, ed. K. R. Jankowski, 147–156. Amsterdam: John Benjamins.
Yates, Frances A. 2001 [1966]. *The Art of Memory*. London: Pimlico.
Zonca, Vittorio. 1607. *Novo teatro di machine et edificii per uarie et sicure operationi: co[n] le loro figure tagliate in ramé e la dichiaratione e dimostratione di ciascuna: opera necessaria ad architetti e a quelli ch' di tale studio si ditettano*. Padua: Pietro Bertelli.