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Geomat.dk: Historical Instruments of Navigation – used as Educational Tools in Mathematics

1.Presentation

Geomat.dk is a non-profit project originally founded as a cooperative project between upper secondary schools and the University of Aarhus, Denmark.

The project deals with surveying and navigation seen in a mathematical and historical light. From our website www.geomat.dk it is possible to download instructions on training, descriptions of instruments, and historical sources for educational purposes.

Schools can borrow collections of instruments with historical and professional equipment for practical hands-on exercises (at the schools or at The Steno Museum in Aarhus).

2.Aims

The project aims at providing practically oriented ways of working with mathematics and science in the upper secondary school. The intention is to make the students aware of and understand the historical interaction between mathematics and surveying and navigation. By handling either genuine historical instruments or museum-like copies of such instruments, they will get a personal experience of what it felt like to make measurements of angles with these instruments and the problems and pitfalls as well as the joy connected with the use of them. All the way we have had in mind that this might open up much broader prospects for the students. Borrowing the title of the novel by Daniel Kehlmann: *Die Vermessung der Welt*, we think that "Measuring the World" is an eminently apt way of describing the broad cultural and historical framework the project fits into and of which we are only lifting a corner of the veil.

The practical approach is tied up with theory in two ways. Firstly, the measurements are done as part of a cross-curricular project with another subject, usually history, but it could also be physics or physical geography. Secondly, the measurements are being used for calculations done in order to

find an important fact about your whereabouts, usually the geographical latitude or perhaps the geographical longitude.

Museums like the Steno Museum (Museum of the History of Science and Medicine) in Aarhus, the Maritime Museum in Elsinore, the Royal Danish Naval Museum, and different local museums have navigational instruments on display in their show cases. The project offers a possibility of actually handling similar instruments outside the show cases.

Contemporary ways and methods in surveying and navigation are certainly interesting, but they are often very complicated and require mathematics that is too difficult. That is the reason why we concentrate on historical instruments and problems – where "historical" usually means not later than the 19th century, often much earlier. Moreover, to really appreciate the modern approach you need to know the historical background.

As this paper primarily is about navigational instruments as educational tools,we shall not go into details about the surveying part of the project

3. History

The geomat project began in 2001, originally mainly focusing on the history of surveying. But shortly after the start the history of the great explorations of the world became a main topic of the project, and therefore the history of navigation and navigational technology assumed a vital role in the project. Geomat.dk became fully operational in 2005 with a website containing written and historical materials combined with the possibility for schools to borrow packages of instruments for doing practical exercises locally at the schools for a period of 3-4 weeks.

In the initial phase the project developed as a cooperation between 6 teachers of mathematics and 2 teachers of history. The work group was financially supported by the Danish Ministry of Education, the Regional County of Aarhus and some private funds. This was combined with several donations of instruments from professionals and a very unique and intense cooperation and support from the technical workshop at the Steno Museum. Most of the museum replicas and repairs of existing instruments were done by this workshop. The donations of instruments were supplemented by regular purchases from instrument makers and dealers from different parts of the world.

4. Present Status

The geomat project itself - the educational products evolved through this project - is an example of how educational features and materials for upper secondary level typically have been developed in Denmark for many years.

The teachers basically develop materials themselves with some support from the universities and the Danish Ministry of Education. Unfortunately, the funding possibilities for developing projects are rather low for the moment (2012) - and the funding for actually running the website and the lending facility for the instrument packages is virtually non-existing. Therefore the geomat project is at present only managed by the authors.

Since 2005, a new, compulsory subject has been introduced into the Danish upper secondary school (gymnasium) - the General Study Preparation (called AT). This is actually a frame for strictly cross-curricular cooperation involving 2 main subjects. Throughout their 3 years of study the upper secondary students have 6 different AT-projects, and often one of these involves mathematics and history using the geomat-materials.

5. Instrument Collections in the Geomat Project

5.1. Surveying Instruments

There is a package of surveying instruments, but as mentioned above we shall omit a detailed description of this. Anyone interested is referred to the website.

5.2. Navigational Instruments

There are three packages with navigational instruments. Each package contains the following items:

A metal sextant (Freiberger), two plastic sextants (Davis Mark 3), an octant from the 1800s, a station pointer of Russian origin (1980s), a replica of a sea astrolabe, two replicas of a quadrant, a replica of a back staff (Davis quadrant), a replica of a cross staff, a box sextant, three artificial horizons, a sea chart of the Aarhus Bay, an almanac for the current year with a table of the declination of the sun, two books and three booklets on navigation, the encyclopedia *Christopher Columbus and the Age of Exploration*[1], a Danish dvd on the history of navigation and a dvd containing the movie *Longitude*. Finally there is a laminated instruction manual for each of the instruments.

The replicas are all carefully made replicas of historical instruments from different museum collections.

[1] Silvio Bedini (ed), Simon & Schuster 1992.

***Figure 1**. Participants of the ICHSSE conference 2012 inspecting one of the cases with instruments. (photo Sebastian Korff)*

The sextants. Sextants are instruments used for navigation up until the introduction of satellite aided navigation (GPS), so they are the most recent historical instrument. The *plastic sextant* is a very primitive specimen, but it has the essential features of a sextant and the use of it can be taught to anybody with only a little introduction to how a vernier scale is used.

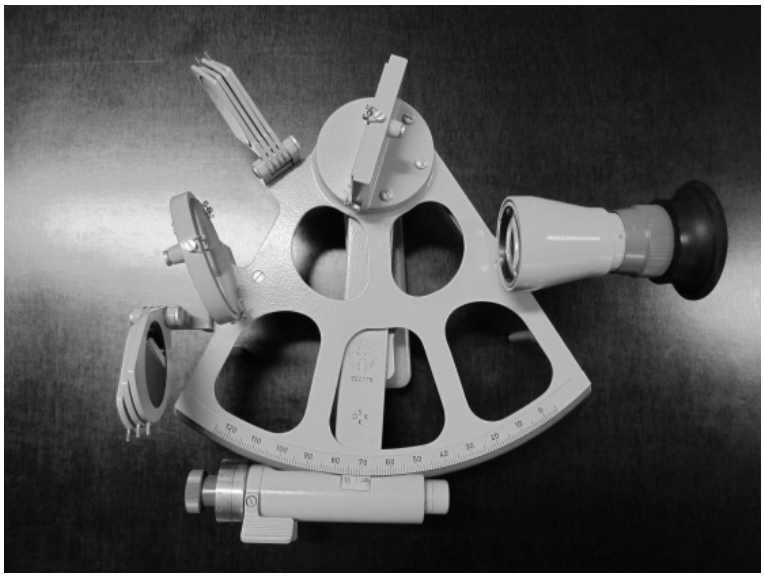


***Figure 2.** Metal sextant (Freiberger)*

The *metal sextant* [fig. 2], made in the 1970s in the former GDR by Freiberger Präzisionsmechanik, enables a really professional approach to celestial navigation – except that in most cases the students have to stay on land and

just imagine the moving ocean under their feet. This instrument is equipped with a micrometer making more exact measurement possible.

Figure 3. *Francis Barker box sextant*

The sextants were developed to be used at sea, but because of their convenient size and small weight they have also been used on land by explorers wanting to make provisional measurements of unknown areas. For this purpose the very small pocket sextant or *box sextant* [fig. 3] was ideal, and the package also contains such an item. As the use of any sextant depends on the user's ability to see the horizon, an *artificial horizon* [fig. 5] is indispensable when measuring on land. As most of the students have to practice ashore, the package contains three simple but efficient artificial horizons to be used together with the sextants or the octant. *The octant* [fig. 4] is only a simpler version of the sextant and is the historical forerunner of the sextant invented in the 1730s. We have found and bought original octants from the middle of the 1800s at internet auctions; the fabrication of a modern replica would have been much more expensive.

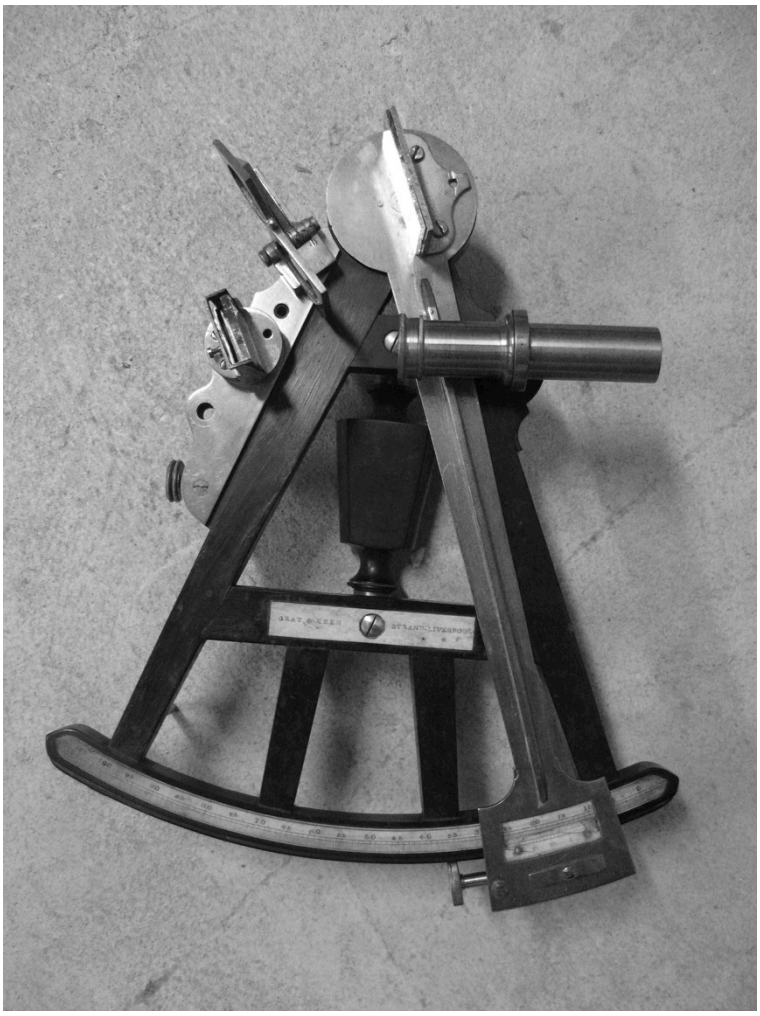


Figure 4. *Gray-Keen octant*

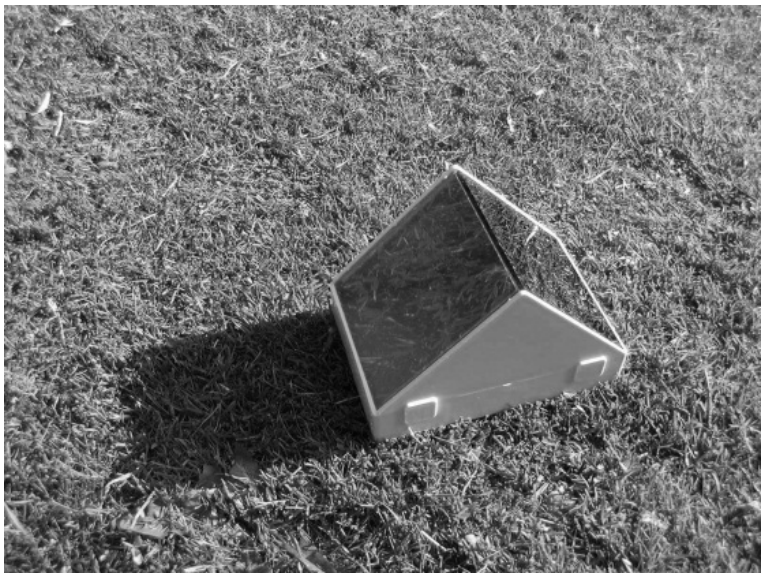


Figure 5. *Artificial Horizon*

Going backwards in history the *back staff*, also called the *Davis quadrant* [fig. 6], can only be used for measuring the height of the sun, as it requires the shadow of a vane attached to the instrument. It was in use from the early seventeenth century to the late eighteenth century. A genuine instrument is too expensive to obtain, but we have had a replica made of an instrument from the middle of the 1700s in the collection of *Aabenraa Museum*. The historically older *cross staff* (also called *Jacob's staff*), which was used from the sixteenth century to late in the eighteenth century, is even harder to come by, but the *Steno Museum* in Aarhus has one from 1720, and the replicas we use in the packages have been made using this as a model [fig. 7]. The measurement markings on the original are, however, so dense that we had to thin them out on the replica in order not to confuse the students.

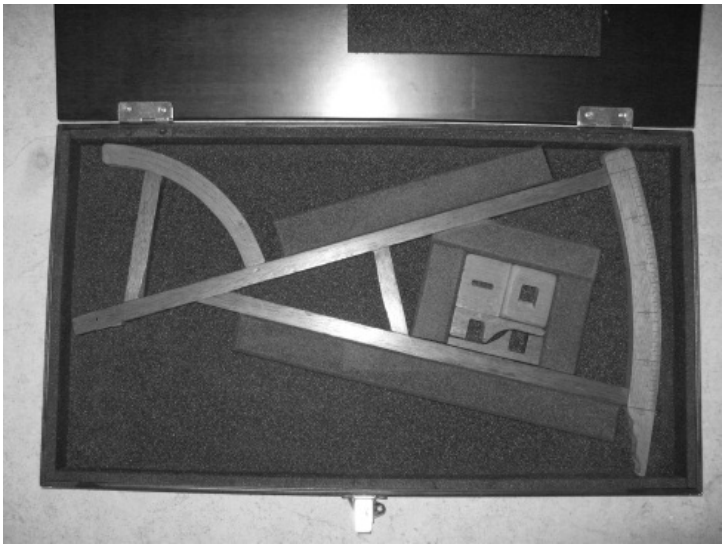


***Figure 6**. Back staff or Davis quadrant*

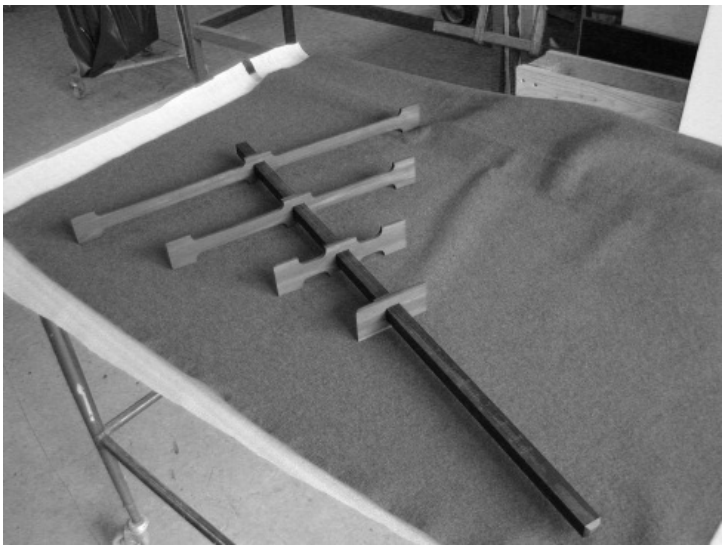


***Figure 7.** Cross staff*

The first angle-measuring instruments to be used at sea in the first wave of exploration voyages were the quadrant and the sea astrolabe.

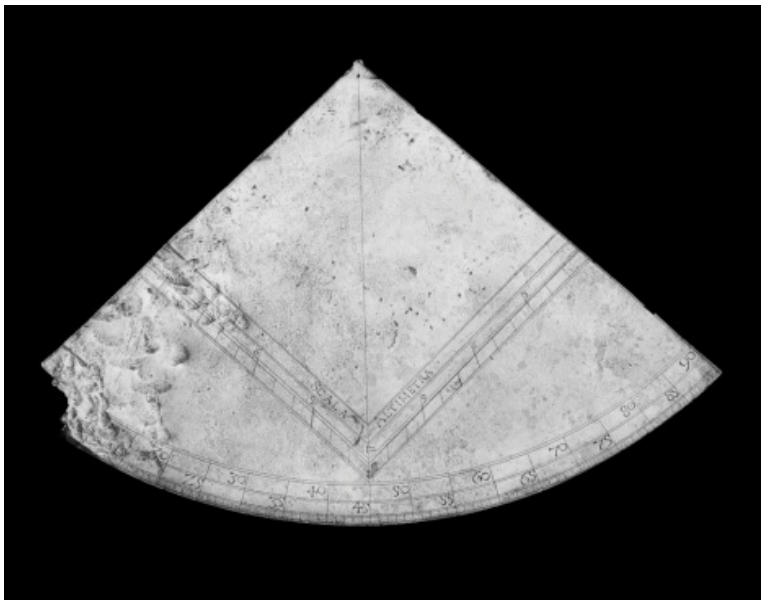


Figure 8. *Quadrant made by Georg Hartman 1547*
(with permission from the National Museum of Denmark).

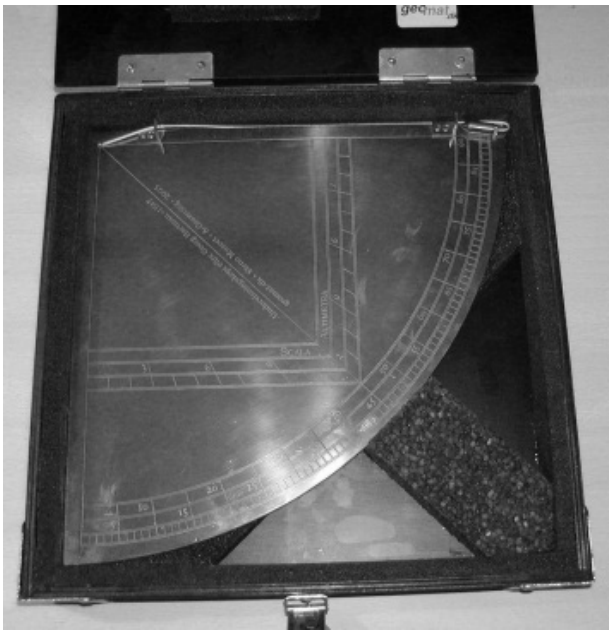


Figure 9. *Replica of the Hartman quadrant.*

At the *National Museum of Denmark* in Copenhagen there is a *quadrant* [fig. 8] made of brass by the German instrument maker Georg Hartman in 1547. We had a replica [fig. 9] made, also of brass, at the Steno Museum workshop, but we had only one side of it engraved with scales, as the other side of the original had more sophisticated astronomical and calendar scales that were

not intended to be used at sea. Finally our replicas of a *sea astrolabe* were made for us by a Swiss instrument maker after drawings and photos of an original French astrolabe from 1632 [fig. 10] which was lost due to bombings during World War II.

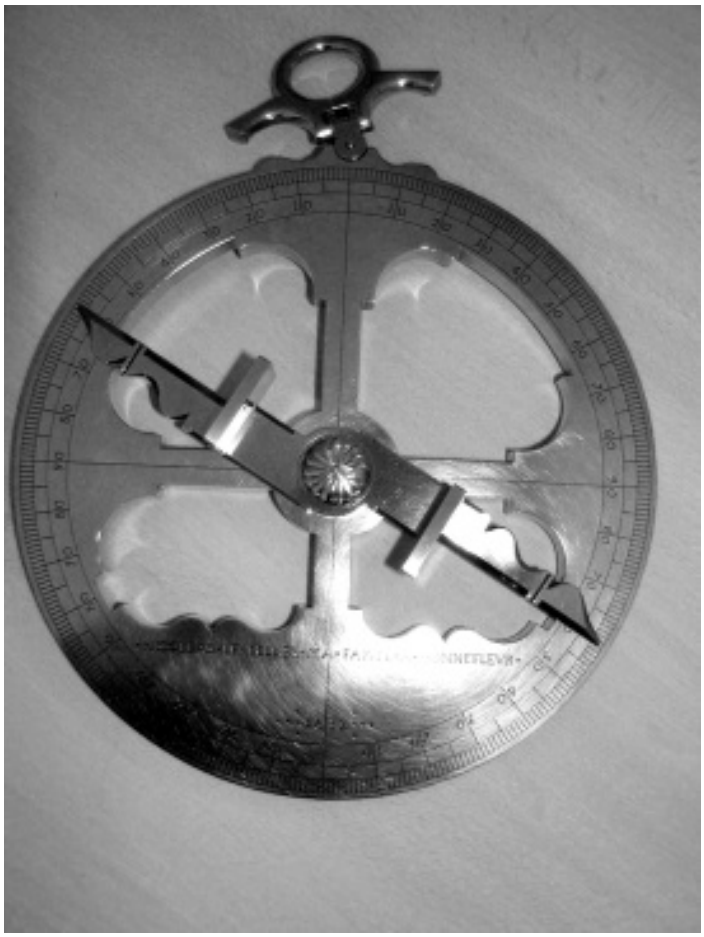


Figure 10. *Replica of a sea astrolabe from 1632, original now lost.*

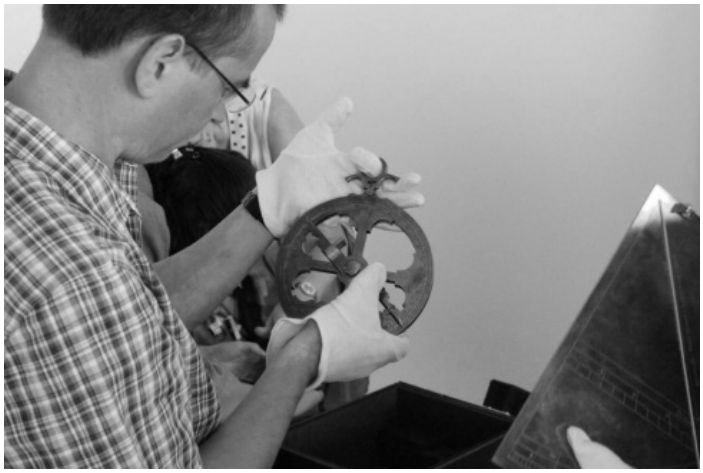
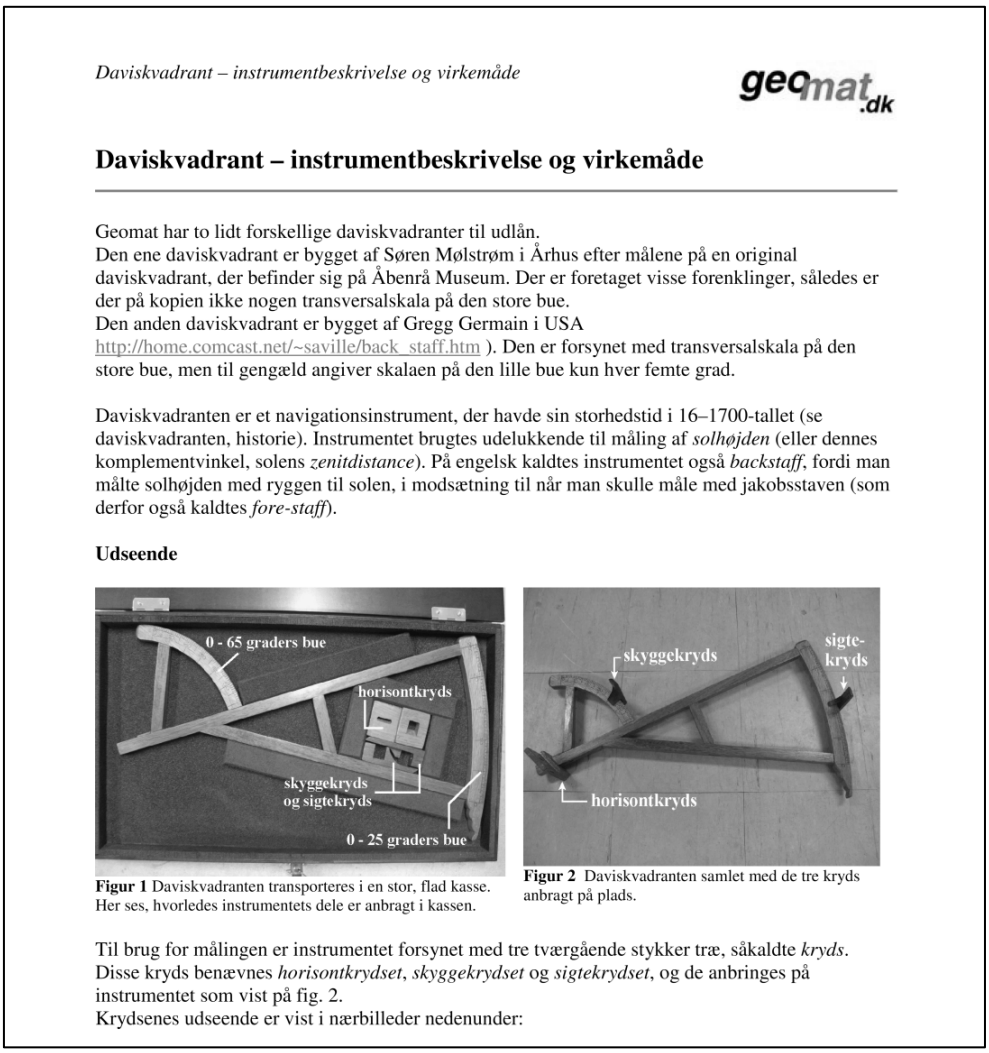


Figure 11. *Examination of the sea astrolabe replica at the ICHSSE 2012 (photo Sebastian Korff)*

6. Website

6.1. Instruments

The website www.geomat.dk contains descriptions of each of the instruments, instructions for their practical use, and in most cases a brief description of their history, too. The figs. 13 to 18 illustrate the handling of the instruments as shown on the website.



Daviskvadrant – instrumentbeskrivelse og virkemåde

geomat.dk

Daviskvadrant – instrumentbeskrivelse og virkemåde

Geomat har to lidt forskellige daviskvadranter til udlån.
Den ene daviskvadrant er bygget af Søren Mølstrøm i Århus efter målene på en original daviskvadrant, der befinder sig på Åbenrå Museum. Der er foretaget visse forenklinger, således er der på kopien ikke nogen transversalskala på den store bue.
Den anden daviskvadrant er bygget af Gregg Germain i USA
http://home.comcast.net/~saville/back_staff.htm). Den er forsynet med transversalskala på den store bue, men til gengæld angiver skalaen på den lille bue kun hver femte grad.

Daviskvadranten er et navigationsinstrument, der havde sin storhedstid i 16–1700-tallet (se daviskvadranten, historie). Instrumentet brugtes udelukkende til måling af *solhøjden* (eller dennes komplementvinkel, solens *zenitdistance*). På engelsk kaldtes instrumentet også *backstaff*, fordi man målte solhøjden med ryggen til solen, i modsætning til når man skulle måle med jakobsstaven (som derfor også kaldtes *fore-staff*).

Udseende

Figur 1 Daviskvadranten transporteres i en stor, flad kasse. Her ses, hvorledes instrumentets dele er anbragt i kassen.

Figur 2 Daviskvadranten samlet med de tre kryds anbragt på plads.

Til brug for målingen er instrumentet forsynet med tre tværgående stykker træ, såkaldte *kryds*. Disse kryds benævnes *horisontkrydset*, *skyggekrydset* og *sigtekrydset*, og de anbringes på instrumentet som vist på fig. 2.
Krydsenes udseende er vist i nærbilleder nedenunder:

***Figure 12**. Beginning of the description of the back staff (Davis quadrant) at the website www.geomat.dk*

***Figure 13**. Student using the metal sextant.*

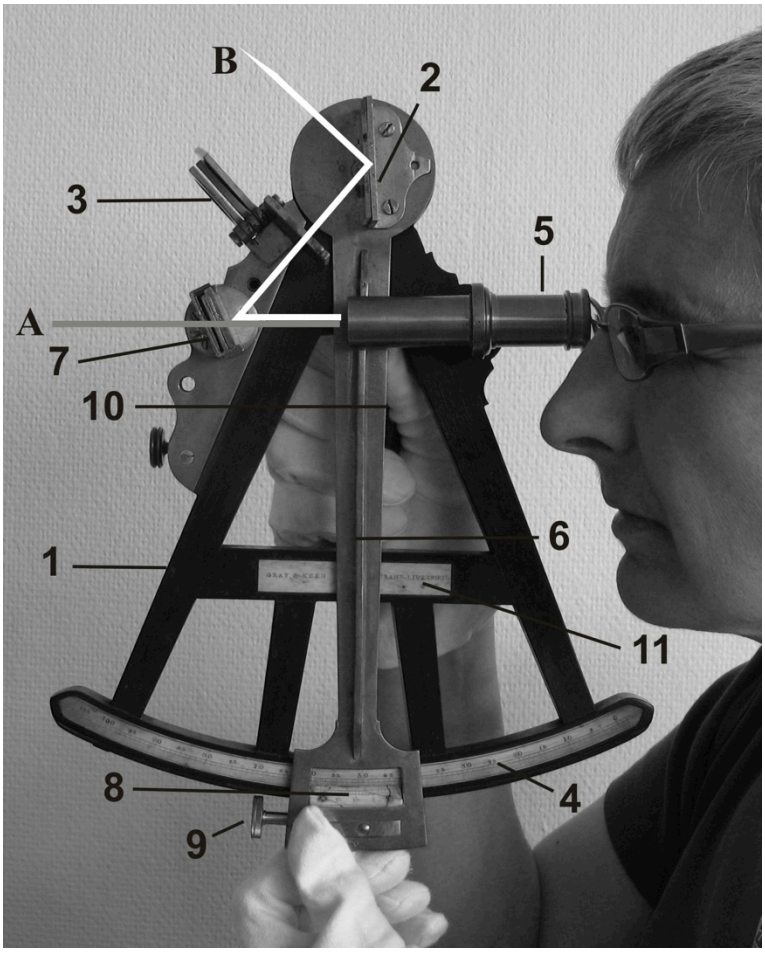


***Figure 14.** Instruction illustration for the use of the octant.*

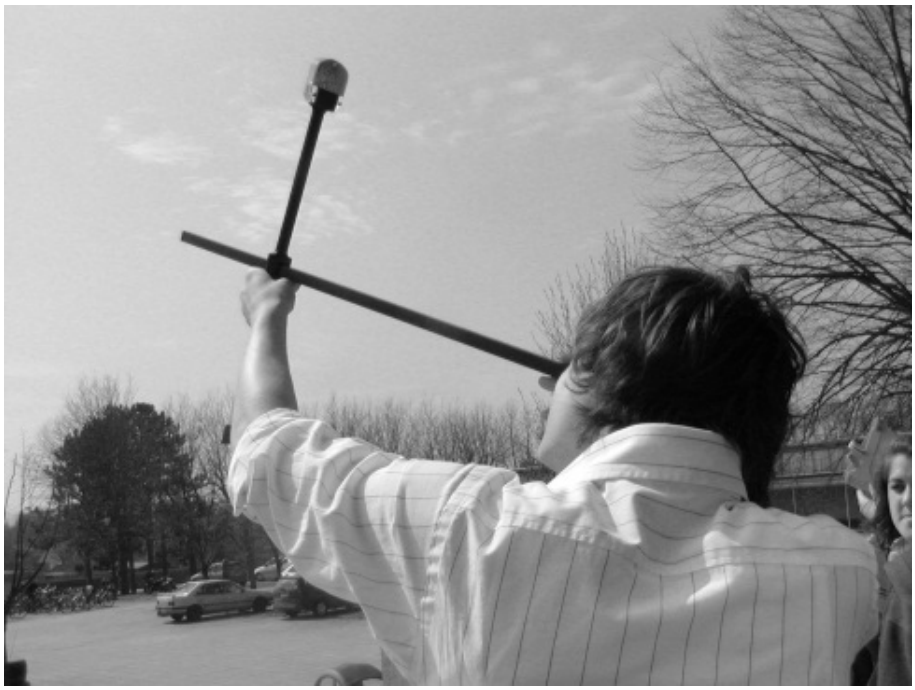


Figure 15. *Student handling the cross staff.*

Figure 16. *Student handling the back staff.*

Figure 17. *Student handling the quadrant.*

Figure 18. *Student handling the sea astrolabe.*

6.2. Historical Sources

The website contains some extracts of historical sources illuminating important events in the history of exploration and measuring of the world. As an example we bring a couple of quotations from Columbus' Journal of the First Voyage:

> Friday November 2 1492
> Here the Admiral took the latitude with a quadrant this evening and found that he was 42 degrees from the equinoctial line, and he says that by his calculations he found that he had travelled 1142 leagues from the island of Ferro, and he still affirms that this is the mainland.[2]

> Sunday February 3, 1493
> The north star seemed to him to be as high as at Cape St. Vincent. He could not measure its elevation with the astrolabe nor the quadrant because the waves would not let him. [3]

These two quotations give in a few lines information about the kind of instruments Columbus used for navigation and the difficulties he had with them. Apparently he carried a quadrant and a sea astrolabe, and apparently he could not use them on board the ship because of the rough water. Furthermore, he used the North Star (Polaris, α Ursae Minoris) to determine the latitude, and not the sun. Finally he found the latitude to be 42 degrees north, which is rather strange as his position, according to later estimations,was somewhere near the northern coast of Cuba and hence at a latitude only half as high.

One of the intentions is to encourage students to make simple and straightforward analyses like these in order to obtain elementary but important information from the original sources. The website also contains some hints as to what possible explanations there could be to the paradox of Columbus' gross exaggeration of the latitude.

Another example: The website contains a few extracts of a *handwritten navigation textbook from 1795* (owned by the Royal Danish Naval Museum), written by *Frederik Grodtschilling* (1782 – 1820) at the age of 13. Through these extracts the students can get an impression of how naval cadets learned navigation by writing their own textbook – or perhaps copying that of an older student? The extracts are transcribed and from them you can get a contemporary description of e.g. how to find the latitude using the height of the sun at noon and how to use dead reckoning to estimate your position at sea [fig. 19 and 20].

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[2] Columbus, Christopher: *Journal of the First Voyage*. Edited and translated with an Introduction and Notes by B. W. Ife. Aris and Phillips Ltd, Warminster, England 1990, p. 67.
[3] Ibid. p.209.

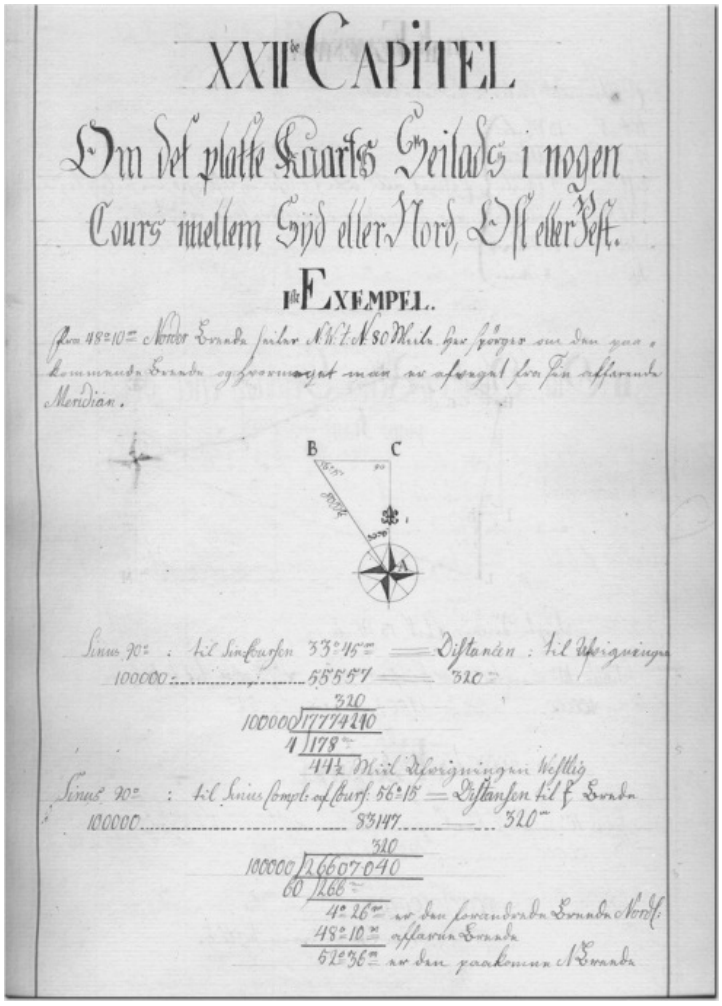

Figure 19*. Page about dead reckoning from Grodtschilling's handwritten navigation textbook.*

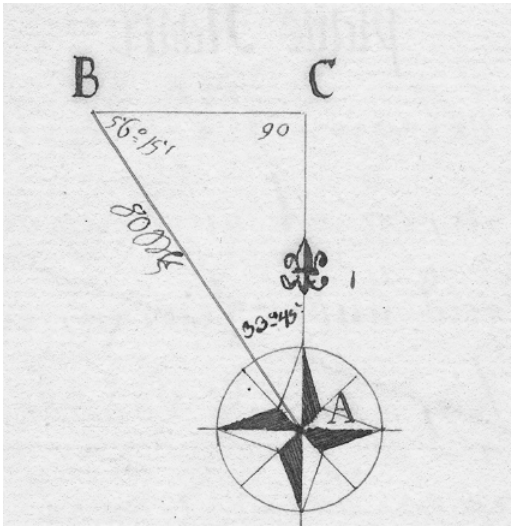

Figure 20. *Drawing of the dead reckoning triangle (Detail of fig. 19)*

6.3. Practicals

The website contains practical instructions as to how to go about finding the latitude by means of measuring the height of the sun at noon, the height of the North Star at night, or perhaps by measuring the height of the sun at two different times before or after noon. There are also some suggestions of measuring exercises if the weather does not permit the sun to be seen.

7. Use Now and in the Future

Up till the summer of 2012 the packages with navigational instruments from the geomat project have been requested by schools 72 times (each time for a period of 3-4 weeks) and in addition a lot of schools have used the materials from the website without necessarily having borrowed the instruments. As intended, the educational materials from the website have been widely used for cross-curricular work (especially with history).

In the near future we intend to supplement the website with some materials about the "navigation" on the ice cap of Greenland used at the Danish arctic expeditions in the beginning of the twentieth century. Furthermore, there are some plans for participating in cross-border cooperation with projects similar to the geomat project.

8. Note on Intention with this Paper

We should like here at the end to stress that the intention with this paper has been to give a short description of the scope and content of the project. We are fully aware that we have not given or collected any systematic evaluation from teachers or students using the website and the instrument packages at different Danish schools. Important as it certainly would be, we have not had the means or the time for making such an evaluation. But we hope to have conveyed some inspiration to others!