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Mathematical Instruments between Material Artifacts and Ideal Machines: Their Scientific and Social Role before 1950

Organised by
Samuel Gessner, Lisboa
Ulf Hashagen, München
Jeanne Peiffer, Paris
Dominique Tournès, Sainte-Clotilde

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Abstract. Since 1950, mathematicians have become increasingly familiar with the digital computer in their professional practice. Previously, however, many other instruments, now mostly forgotten, were commonly used to compute numerical solutions, generate geometrical objects, investigate mathematical problems, derive new results, and apply mathematics in a variety of scientific contexts. The problem of characterizing the mathematical objects that can be constructed with a given set of instruments frequently prompted deep theoretical investigations, from the Euclidean geometry of constructions with straightedge and compass, to Shannon's theorem which, in 1941, stated that the functions constructible with a differential analyzer are exactly the solutions of algebraic differential equations. Beyond these mathematical considerations, instruments should also be viewed as social objects of a given time period and cultural tradition that can amalgamate the perspectives of the inventor, the maker, the user, and the collector; in this sense, mathematical instruments are an important part of the mathematical cultural heritage and are thus widely used in many science museums to demonstrate the cultural value of mathematics to the public. This workshop brought together mathematicians, historians, philosophers, collection curators, and scholars of education to address the various approaches to the history of mathematical instruments and compare the definition and role of these instruments over time, with the following fundamental questions in mind – What is mathematical in a mathematical instrument? What kind of mathematics is involved? What does it mean to embody mathematics in a material artefact, and how do non-mathematicians engage with this kind of embodied mathematics?

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Introduction by the Organisers

What is a mathematical instrument? The main aim of the workshop will be to question and make precise the meaning of this expression prior to 1950, that is, before the appearance of the digital computer. Instruments have been seen in very different ways in different mathematical cultures, which is one of the reasons we now have trouble characterizing the situation in a global and definite way. For example, at particular times, certain types of tables were seen as instruments and not distinguished in terminology from a brass, wooden or paper instrument performing the same function. Referring to two major ancient surveys, there are deep differences between the definitions and classifications found in Nicolas Bion's *Traité de la construction et des principaux usages des instruments de mathématiques* (1709), compared to those found in Friedrich Willers's *Mathematische Instrumente* (1926). The changing role and character of mathematical instruments is a sure reflection of the changing nature of mathematical disciplines generally, so there is a danger, in using too narrow a definition, of missing some important conclusions that might otherwise emerge. It is safer, therefore, to allow 'instrument' in the various epochs we will cover to mean what the contemporary mathematicians (again perhaps self-defined) took the term to mean. Fortunately, similar words are used in the language traditions we are likely to cover, and so terms such as 'organon', 'machine', 'device', 'apparatus', etc., are all valid.

In the earlier period there are many instruments that perform, what we would consider, mathematical operations, and so have necessarily been designed by people with mathematical skills, but whose professions and services may not immediately appear mathematical to us – surveying, navigation, cartography, artillery, etc. The 'mathematical' operations are not explicit – they (at least from our viewpoint, but perhaps not as seen in the period) are contained within the operation of the instrument. Astronomical instruments such as astrolabes, quadrants, Ptolemy's rulers, and equatoria, were the most common mathematical instruments for a long period during the Middle Ages. They exploit, to a large extent, geometrical properties in a clever way to transpose between coordinate systems or metrics. Dividing their scales and accurately adjusting them to parameters such as latitude or epoch would have required considerable mathematical skill. Another example is that of perspective machines, which represent an embodiment of a mathematical theory, even if this was not always perceived by the users of these machines. More generally, mechanical devices such as compasses, slide rulers, levers, balances, etc., were largely used by non-mathematicians (until today).

For the historian, one of interesting features of mathematical instruments is that they stand at the crossroad of the making and the use of material artefacts, and the development of abstract concepts, methods and theories. They are involved simultaneously in technology and mathematics (here we think of 'pure' mathematics as well as 'mixed' or 'applied' mathematics where these distinctions make sense). In the early days, the approach to mathematics was perhaps a more mixed one. From Nicomedes's conchoid tracer to Galileo's sector to Oughtred's circular slide rule, geometry sometimes experimented with using more than just

compass and straightedge, and the calculators sometimes used graphical means to make approximations. Up to and including mechanical calculating machines and differential analyzers, all these tools permitted mathematicians and other scientists to experiment on numbers, curves, functions, and solutions of algebraic or differential equations in order to make conjectures and develop new theories. The rigorous and clever use of these devices was also closely linked to the creation of numerical and graphical methods of calculation that gave birth to numerical analysis as an autonomous discipline at the beginning of the 20th century. Far from actual calculation and measurement devices, mathematical instruments could be also thought of as 'ideal' machines: mechanical linkages described by Descartes, or tractional integraphs imagined by Leibniz and Vincenzo Riccati were not introduced at first to be manufactured and employed for actual use, but conceived for theoretical purposes, as a way of legitimizing the use of new curves and new types of constructions in geometry. Thus the situation appears complex: the workshop will have to examine, in depth, the creative and genetic role of instruments in the development of mathematics.

In studying mathematical instruments, the interaction between different group cultures and different mathematical traditions inevitably emerges, so our workshop will not neglect a more social approach. It starts from the observation that, at least in the ancient times, scholarly mathematics was mainly promoted by people with university training, who knew Latin (and sometimes Greek), who also had a rhetorical and methodological training in how to think and write; instrument makers did not generally have such an education. Nevertheless, the makers had access to a mathematical tradition, in part oral, in part written, that allowed them to often think of the same questions and problems as the scholarly people. On the subject of interaction between artefact and theory, this is not something necessarily associated with one mind, one inventor, one mathematician – it could also mean interaction between people from different groups, between those who materially and technically assemble instruments and those who offer theories on mathematical properties. Instruments are also what their users make them. In the history of technology, which sometimes comes close to that of mathematical instruments, one can write a narrative from the point of view of the makers, but also from the point of view of the users. This raises questions such as – What do these instruments stand for, and how are they designed, discussed, made, promoted, sold, used, explained, taught, represented, and advertised? Why were they bought, admired, published in so-called theatres, etc.? And also, of course, where were they collected, displayed, etc.? All these social interactions are what make mathematical instruments such unique research object. They are conceived, but also built (where? how? by whom?) and they are not used exclusively by mathematicians; that is to say that we have a large array of interested parties, and each needs to be considered and studied.

Many books and papers have already been published on the subject of mathematical instruments but, in our opinion, the majority of these studies have been

conducted in too independent and specialized a way by mathematicians, philosophers of science, historians of mathematics, historians of computing, historians of astronomy, historians of technology, historians of engineering, museum conservators, private collectors, and researchers in mathematics education. The novelty of our workshop is that it gathers scholars from all these communities to work together. Regarding the organization of the meeting, we will try to balance general sessions devoted to defining, characterizing and classifying mathematical instruments at different times – taking into account the points of view of the different individuals involved – with specific sessions devoted to certain periods, certain geographical regions, certain areas of mathematics, certain professional milieus, certain types of instruments, or certain social aspects of their intervention. We hope that this will give rise to new insights into this broad-ranging subject and stimulate future, pertinent investigations.

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