Mathematics and the Medici Instruments from Late Renaissance Florence and a British Connection

Dr Jim Bennet

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For some years I have been working on a catalogue for publication of the mathematical instruments, at not the Museum for the History of Science in Oxford but in Florence. I thought that an overview of this collection would make an appropriate lecture, and I hope an entertaining lecture as well, because, among the reasons for my choice, I will be able to show you lots of very fine things. The instruments are beautiful, they are interesting, they are ingenious often, there are plenty of them - if you find one a bit boring, there will be another one along any minute! So I hope that, in that sense, it will be visually an enjoyable experience. It gives you a good excuse for visiting Florence, because clearly you will have to visit Florence after you have seen my slides and you will have to see the real thing. Actually, come to think of it, you should not visit now because they have closed the Museum galleries - I've just remembered; they will re-open in autumn of 2009. Prior to that, there is a big Galileo exhibition n Florence, so you will have to go and see that, and then you will have to go back again to see the re-opened galleries in the Museum of the History of Science; so you now have two obligations to go to Florence, which of course is very tiresome for you I know, but placing this obligation on you by coming to the lecture is part of my plan!

More particularly, and more seriously, there are general lessons to be learnt about the nature of mathematics and the Renaissance from this, and I would say, uniquely, from this collection. As historians, we are used to using manuscripts and books and so on; this is a different historical resource, material culture, as it is fashionably called: objects. Particularly these objects, more so, I would say, even, despite its distinction and despite the size of the collection in Oxford, I think the collection in the Museum of the History of Science in Florence has more to teach us. The reason for that is that the collection, uniquely, to a very large extent, is natural - it happened in time, in history, in its space; it happened naturally, it grew up through the practice of mathematics in Florence, it has stayed where it began, where it was collected, where it was used - though quite what that use was is interesting to speculate.

That is not true in Oxford. The Oxford collection is an artificial collection. A collector called Lewis Evans decided, in the late-19th, early-20thCentury, that he would collect scientific instruments. He put together a collection of great distinction and then it was added to, but it was a collection of his view of what scientific instruments were. Now, it was partly his view, but it was also partly the view of the sale rooms - Sotheby's had a role in the category that was created for the Museum, the dealers had a role, and so on. So, for instance, you will find in the Museum of the History of Science all sorts of things together that in their historical context were disconnected, quite unconnected with each other. For instance, we have lots of sundials and we have lots of microscopes. Microscopes and sundials, despite us thinking of them now within this collective category of scientific instruments, actually, historically, have nothing whatever to do with each other, so that the construction which informs the collections in Oxford is an artificial one. It was created much later than the objects themselves, so that while the individual objects have things to teach us, the collection is actually misleading in its overall scope.

I am not merely denigrating my own institution; that is true of all the other institutions. In Cambridge,

Robert Whipple was the person who made this construction, again working in the same tradition, largely established by Lewis Evans. Just thinking of the fine collections of early mathematical instruments, in Greenwich Sir James Caird had a lot to do with it. Of course, It is often the dealers, finding a rich customer, who will construct this category for him - usually "him" - and the dealer of course has an interest in putting together the things that he has to sell and and that are available, so there are all sorts of reasons why collections take the shape they do that have very little to do with history. If you think about America, the Planetarium is artificial. I am afraid they are all artificial, but the exception is the Museum in Florence. I am not saying it is entirely natural, because there are instruments that have come in later. But because it has always been kept in Florence, within this tradition, in the Medici Archives, then we know which ones are intruded. The record is difficult to handle - it is a bit intractable - but it is there, and with a bit of scholarly research, you can work out what really was in the collection to start with. In that sense, we can reverse the process: instead of creating the collection from our idea of what scientific instruments were in the past, and then we collect them because we think that is making a coherent collection, and we are probably misled in that respect by lots of other agencies, like dealers, and sale rooms, and other people who are trying to convince us of their agenda, we can reverse that process, we can look at the collection in Florence, and we can learn what scientific instruments were, more particularly, in this case, what mathematical instruments were. So individual instruments can be a source, but a natural collection is a much better source.

The collection is in the Museo di Storia della Scienza, in Florence. If you know Florence at all, you will know the Ponte Vecchio, the Uffizi Gallery, and just to the back of the Uffizi Gallery is the Museum of the History of Science, in the very central tourist area of Florence. There is a lot of competition for visitors in this area, but of course there are many, many thousands of visitors, and many of them will find the Museum of the History of Science.

What we are concerned with here are the Medici Collections, the collections of the Grand Dukes of Tuscany. Since, for once, we do have a natural collection, I want to make the most of this by setting it in context, giving you a structure, through the Grand Dukes of Tuscany who were involved with this collection in the first century or so, and, as I say, the Medici rulers themselves and the places where these instruments were kept.

Remember that usually there is no provenance at all for instruments of the type we will be seeing. The instruments in my Museum in Oxford, frankly, we know nothing about who originally owned them or what their history was. The earliest - we can trace them back to when Lewis Evans, the chap I was talking about at the start, bought them. He might have kept a record, that he bought this at a dealer in Paris, or he bought it at Sotheby's or something like that, and you will never find out from those dealers where they got it from - that is of course a trade secret, they are not going to divulge that. You might see their archives when they pass on, but probably not, so that is lost to us. It is unlike fine art, where the provenance of the painting is part of what you are buying when you engage in this market. It is not like that in my world at all, never has been I guess, and so the provenances have not survived. Uniquely in Florence there is something to say about this.

I will begin the story with Cosimo Primo, Cosimo the First, the first Grand Duke, previously Duke of Tuscany, and then Grand Duke of Tuscany, who begins the collection in the 16th Century. It is not surprising that this collection begins in the 16th Century; there is something very natural and, from a historian's point of view, expected about that, because we know, from published books and so on, that it is in the 16th Century that mathematical instruments begin to be prominent, begin to have a vibrancy, and a development, and an ambition and a range and scope that they did not have before. Something interesting happens in the 16thCentury in relation to practical mathematics and its instrumentation, so it is not surprising that our story begins in the 16th Century.

I have a portrait by Bronzino. It is not a snapshot or something, you know, he is presenting himself in a particular guise, in a particular role. He is clearly a man of action, a worldly man, a man of power and

influence and military record and success; very clearly an ambitious ruler. He has an equestrian statue that you may well know in the main square in Florence where, again, this man is saying something to us about who he is.

He forms this collection of mathematical instruments. So immediately, we begin to see the placement of these mathematical instruments in a culture, in a location, in a context that maybe is not what we associate with mathematics, where we tend to think of something more scholarly and something more abstract and solitary. That is not Cosimo's way; that is not Cosimo's role. Cosimo had a special room made for his instruments, for his precious things in general, but instruments were prominent among those, in the Palazzo Vecchio in the middle of Florence. I will say a little bit more about that later on, but that is going to be an important part of my story.

Francesco, his son, the following Grand Duke, looks a bit more like a mathematician. I think he probably does conform a little more to what we would think of as the scholar, and indeed he was more of a scholar, but he was much less of a mathematician. He was not very interested in the collection at all; it was not his thing. He was the more studious, the more introverted, I would say, more obsessively concerned with the natural world and its correspondences and meanings, in a way that Cosimo was just kind of no-nonsense, out there sorting things out, Francesco was a much more thoughtful and studious person, but in fact was not very interested in mathematics and in mathematical culture and in the instrumentation. So again, that perhaps is a little more surprising.

The instruments are moved in 1600, when Ferdinando I transfers them to the successive Grand Dukes. I think this gives a structure to what is going to happen - he transfers them to a small, purposefully organised room in the nearby Uffizi Gallery (the Uffizi is just next door), a room that becomes known as the Stanzio della Mathematica: the Mathematical Room. It is clearly deliberately organised because even the frescos on the ceiling are all mathematical allegories in various ways, and some of the instruments in the collection are actually depicted on the ceiling - the very things that are in the room are painted on the ceiling as well.

I will mention Cosimo II, Ferdinando's successor, partly for completion because we want to have all these Medici in there, but also because of Galileo. He was the Grand Duke in Galileo's time, from whom Galileo wanted to receive patronage, to whom Galileo dedicates the "Sidereus Nuncius" in 1610, and who indeed eventually takes Galileo on as a client - what type of client, I will talk about a little later, if there is time. Cosimo II does not do very much with the collection, but Ferdinando II, who is the succeeding Grand Duke does have a part in the story, on account of his joint sponsorship of a scientific society. He sponsors it jointly with Prince Leopold, who does not become Grand Duke, but the two of them together, and Leopold perhaps in particular, are influential in the foundation and organisation and management of the Accademia del Cimento in the mid-17th Century in Florence. I want to mention that because of its clear links with where we are this evening, with the Royal Society, and through the Royal Society, with Gresham College, because the Accademia del Cimento, although it came before the Royal Society, is one of these pioneering organisations for the promotion of the new experimental philosophy in the mid-17th Century. The Accademia met in the Palazzo Pitti on the other side of the river, and there we will end this succession of the move of the collection around what have become these major tourist sites in Florence today.

Leopold had quite close connections with the Royal Society in particular. He was a correspondent. The Society, the Accademia del Cimento, represents why I want to end there, when I come to the end of my talk - I am just setting out the skeleton now - I want to end there because the Accademia represents a very different use of instruments, and a new threshold is reached when we deal with the Accademia's use of instruments, but we have also passed another threshold, as you will see when we talk about Galileo and the telescope. So, in a sense, we can take the activity of the Accademia as a kind of limit or threshold of our study, a moment when instrumentation in Florence takes on a different role, and, as I say, another moment is the telescopic work of Galileo. I will come to these later, but I want to stress that, until that moment, what we are dealing with, in the terminology of the time, are mathematical instruments. It is very important to maintain that terminology.

I have loosely talked about scientific instruments from time to time, for reasons of familiarity, but that is actually very misleading. Mathematical instruments is the category of the period, and I want to keep that in mind, because it may not always seem to you as though we are dealing with instruments of mathematics. We might think of that as drawing and calculating and so on. As you will see, you have to expand that notion enormously in order to accommodate the way the term was used in the 16th Century.

A good way to address that, this expansive category, is to look at the original setting. We have looked at the figures who were involved, the patrons who were involved in establishing and developing this collection; what about where it was kept, and particularly its original setting? I want to go back now to the Palazzo Vecchio consider the room that Cosimo I had refurbished and decorated for this purpose, in the Guardaroba, in particular to keep his mathematical instruments. It was the wardrobe of the Palazzo Vecchio, known today as the Sala delle Carte Geografiche, the Map Room.

If you're interested in cartography, you might have visited it, and it is on the tourist route through the Palazzo Vecchio. It is very deliberately, very carefully, and very imaginatively organised and planned - planned more than organised because it was never finished, but there is a very elaborate, very well worked out plan, which Giorgio Vesari was very involved in setting out. He attributes the plan to the Grand Duke, to Cosimo himself. Whether that is true or not, who can say? One did that in those days; one gave the Duke the credit. So between Giorgio Vesari, whom you will have heard of - there is a television programme, I understand, on BBC - but Giorgio Vesari, author of "The Lives of the Artists", with Cosimo, sets up this room for the placing of the mathematical instruments and other things.

The one part of the room that was finished was the maps. All around the room, there are maps, laid out according to the arrangement in Ptolemy's Geographia, or Cosmographia as it was more often called in the 16thCentury. Originally the plan was for the ceiling to have the constellations, so you have the Earth at one level and the ceiling had the constellations of the heavens, and then in between, at the level of the tops of the maps, there were going to be, according to Vesari, portraits of several hundred famous men and busts of important rulers. So between the worldly sphere, represented by the maps, and the heavenly sphere, represented by the constellations, there was the scene of the achievements of men of action, men like Cosimo Primo of course, who was placing himself in this scheme, which he would have thought of, and which would have been thought of in the 16th Century, as a cosmography. That was the term that would have been used.

Cosmography was an important and popular discipline in the 16thCentury, and many people cultivated this thing called cosmography. How did they cultivate it? Well, they bought books about cosmography. One of the most popular books of the 16th Century, certainly the most popular mathematical book of the 16th Century, was called "Cosmographia" by Apianus, and of course you could buy much more sumptuous cosmographies as the century wore on. You could buy globes, which were cosmographical instruments, and so on. Another type of cosmographical instrument was a sundial, believe it or not, because the whole meaning of cosmography, the whole dynamic of cosmography, was to say that the heavens and the Earth are linked: they are to be seen as one; they are closely related to each other; what happens on the Earth has a close relationship to what happens in the heavens. There are lots of ways that that link is made. For instance, astrology would have been predicated on this notion of the cosmographical unity of the entire cosmos, but perhaps at a more mundane level, calendar, seasonal change, time, were part of this integrative discipline which was called cosmography.

The plan is not lost on the 16th Century. One of the reasons why Cosimo cultivated cosmography was there was a kind of pun going on between Cosimo and the clients who provided him with cosmographical product, like the map room. Cosimo was very keen on all of this. He planned this room to have, as I say, the maps round the walls, the ceiling with the constellations, the stage of worldly achievement in between. Not contented with that, Cosimo was a great showman. The room was never finished but, had it been finished, you would go in with Cosimo, and there was to be a secret lever which, if thrown, compartments in

the ceiling would open, and down would descend two great spheres. Spectacle was part of the mathematician's role in the 16th Century. Two great spheres would descend: one, a geographical sphere, like the sphere by Egnazio Danti; and the other a celestial sphere. So that the cosmographical sphere knitted together all of those maps around the wall, and the celestial sphere showed you how all the constellations were put together in the sky. The celestial sphere had movement and was a kind of spherical astrolabe.

The only thing that was missing from this cosmography was the Sun and the planets. Cosimo was not going to leave anything out, and there was going to be a clockwork orrery, a representation of the planetary motions, made by the leading clockmaker, and indeed instrument making dynasty, in Florence in the 16th Century, a man called Lorenzo della Volpaia. Volpaia was going to provide the representation of the planets.

So a lot of the people involved with this. The man who was the scholar, the cosmographer, in terms of scholarly cosmography, was a man called Miniato Pitti, who was an Olivetan monk. If you know Florence, he was the Abbot of San Miniato al Monte, on the other side of the Arno. He was a member of the Pitti family, he was an aristocrat, but he was an Olivetan, and he was a cosmographer of some distinction in 16th Century Florence, and he was the person who determined the arrangement of the maps in relation to Ptolemy.

The maps were begun by a man called Egnazio Danti, who was a Dominican. It is interesting how many religious orders are involved in making this room. Egnazio Danti began by making the maps, and then, when Cosimo dies, you remember his successor, Francesco, is not too keen on mathematics. He had been taught mathematics by Egnazio Danti as a young man, and he had hated it all, so as soon as he became Grand Duke he dismissed Ignacio. Danti lost his job. So you had to be careful as a mathematical tutor - it might come back to haunt you. He is kicked out of Florence, it is quite serious, he does not want to go, but off he goes, and he is replaced, to complete the maps, by a man called Stefano Buonsignori.

There is a little room that Francesco creates in the Palazzo Vecchio for his things. It is a very different place. It is the Studiolo. It is a place for private contemplation. Only the Prince is admitted. There are indeed cupboards. Behind them is where the objects are kept. It is really, essentially, a very grand storeroom. This is the storeroom of Francesco. It is very different. It is to do with natural philosophy, he has got minerals and so on, and above all it is a private, enclosed space where the Prince goes to think about things and to contemplate and to be the Prince. Being the Prince, for Francesco, is a very private and intimate business, whereas for Cosimo it is a worldly business - you bring in the people you want to impress, you have great globes coming out of the ceiling, you are showing off, you are being that chap in all that armour and so on. He is the mathematician. Francesco is not interested in mathematics. I hope this is giving us a different view of where mathematics is in the 16th Century from where we might expect.

Because this is a natural collection, the people I have mentioned, who were involved in the making, or the failing to complete, frankly, but in the scheme for this room, they are all represented in the collection.

For example, there is an orrery quadrant made by Miniato Pitti, and it s in the collection. It is for finding the time. It finds the time by the altitude of the Sun. It is made of wood, which is typical of Pitti's work. There is a quadrant which works by the altitude of the Sun. Most of our sundials that we know work by the hour angle, by right ascension, but this works by altitude, because of course the Sun gets higher in the sky to noon and then it goes down and sets in the West, rises in the East, and so on, so you can relate a measure of altitude to some measure of time. It is always a bit confusing explaining altitude, orrery quadrants - the crucial bit is always missing! The plumbline has always disappeared, and we curators, being very fussy types, don't replace it with a nice piece of modern thread, but there should be a thread hanging down, with a bead on it, and so as the day progresses, you start with a horizontal line, because you are viewing the Sun on the horizon, and as the day progresses, if you are following the Sun with an instrument like that,

your plumbline is going to go across and back again - across to noon, the highest, and then back again - and you will have a bead, adjustable on the thread, which will give you the time. Remember that time is one of the important variables in cosmography. So it is not surprising that an instrument like that is in the Guardaroba.

Remember I mentioned Egnazio Danti? There is a beautiful instrument, possibly one of the finest things in the collection, an instrument by Egnazio Danti, a gilt brass instrument. Believe it or not, there is a trigonometrical table. It is a table for sines and versed sines. It has a quadrant, just the angles to 90 degrees and one scale is the right sine, and another scale is the versed sine. Now, if you don't remember what that is, I just have a diagram I found on the internet the other night. Remember that this is geometry, so they are thinking about trigonometrical functions in terms of lengths, so it is the length to a particular radius. In other words, for the radius, OA, AC is the sine, and CD is the versed sine. If we go back then to the instrument, then you just find the sine. You just take your line across, it could be a thread or something, and you can read off either the sine or the versed sine. At the centre is the Medici arms, a reminder of the patronage situation of mathematicians in the period. This is clearly an instrument for Cosimo.

Patronage is a variable thing. Egnazio Danti was not the inventor of one instrument, but Apion, whom I mentioned as the cosmographer of the period, was the inventor. There is in a book of Apion's exactly the same instrument - you see on a piece of paper, with a thread for doing it. He has "Insignia Christophia Stadion Episcope Augustini", the crest, arms, of Christopher Stadion, the Bishop of Augsburg, who is, as you will guess, Apion's patron. The shape echoes the motifs in the Bishop's arms. So they are up to all those dodges to show that mathematics is useful to the Prince and patronage is part of this game - not a game, sorry, it's a living!

I said that Buonsignori took over from Danti for doing the maps, and there are polyhedral sundials in the collection by Buonsignori, absolutely gorgeous, extraordinary things, again with the Medici arms, so Buonsignori is making sundials as well as doing the Carte Geografiche. There are four sundials, in a single instrument. You might wonder why are there four. Well, there are four because the particular instrument depends on latitude. So you choose which latitude is closest to the latitude that you are using it in. Okay, it doesn't really matter because it is very inaccurate, but it is part of the pleasure of enjoying how the Sun works, and how time works in relation to the Sun, that it varies with latitude. Obviously, we know it varies with latitude, but what is nice here is that it is telling the time in what are called Italian hours.

Italian hours begin at sunset. Sunset is zero. It is a 24-hour system to the next sunset. You can see the hour lines. There is 12, 13, 14, 15, 16, 17, 18, 19, and so on, and there is a pin nome and the tip of the pin casts a shadow on the set of hours. It casts the shadow in a different place depending on the time of year. In the summer, at the Summer Solstice, when the Sun is highest in the sky, then the shadow is moving around on a particular path, and the day is long, and Sun is up, for the hour lines. In the Winter Solstice, the Sun is moving around on another line, the day is shorter, and in the Equinox, it is going around in a mid-line and so on. But as you go round, 14, 15, 16, 20, 22, 23 - 24 is always on the edge because the Sun is on the horizon, so it always has to end on 24 because 24 is sunset always in Italian hours. So you can begin to see the pleasure of owning and understanding a thing like this.

The planetary clock was made by a man called della Volpaia. There are about five or six Volpaias in a family dynasty - they are making instruments as well. There is a lovely quadrant which I think shows the altitude quadrant telling the time in Italian hours. Now, you are becoming an expert in this business of hours and Italian hours and so on, and this is another altitude dial. There are two sights. If I had one of these with the Sun on the horizon, in the east, at sunrise, and then at sunset, I would be moving my quadrant up to noon and then I would be going down again to sunset. There is a line for the morning hours, when the Sun is on the horizon, and there are morning hour lines, solid lines, and there was a line which hangs down, a string, and a bead, and you put the bead one place for the Summer Solstice and you put another place for the Winter Solstice, and there is a zodiacal scale. For the Summer Solstice, you are

going right up to 12 noon, and then back down again, and as the year progresses, it is doing that, as you go through the year, until the winter, and you can see the morning hours, 10, 11, 12, 13, 14, and so on, and then you can see 19, 20, 21, 22, 23, and always 24, because it is on the horizon as it sets. Volpaia, nicely, helps you out, because it is quite confusing, this pattern of hours. You have dotted lines for post-meridian, and solid lines for anti-meridian, so morning and afternoon hours are separated out so that you can see them more easily.

There is a very beautiful instrument by della Volpaia in the collection, which is for telling the time at night. That sundial is all very well during the day; how are you going to tell the time at night? Well, you need some sort of progressive movement, and the progressive movement that you use is the rotation of the celestial sphere about the Pole. There is an instrument, which I have not got time to talk about now, sadly, which does just that, indexes the rotation of the celestial sphere and makes an adjustment, you will realise, which is required for data. Time telling is going to be an important aspect of the collection. Remember, all these instruments I am talking about are in the Guardaroba; they all belong in there. We might as well begin with something that you are not surprised to find, a couple of astrolabes. I won't go into the astrolabe in any detail. There would never have been time, but there certainly isn't the speed I'm going at. There is a nice astrolabe by Georg Hartmann, a very famous instrument maker, astrolabe maker in particular, from Nuremburg. The Medici had a nice astrolabe from Nuremburg. They had a lovely astrolabe from Louvain, by Walter Arsenis. These are two classic astrolabes from the European tradition in the 16th Century, from Nuremburg and from Louvain, and they are very different. Typical of the Arsenis tradition is the pattern, which is a kind of planisphere, with lots of points for the stars and a circle for the Sun, and they always have a tulip in the middle, as a nice signature design element.

Perhaps you are less likely to expect an instrument like the two sights for a gun, two sights for aiming, for levelling, for inclining the gun. By gun, I mean a big gun, a cannon you would say. The sights make sure that the elevation of the gun is such that the trajectory is going to hit the target. That is a mathematical business in the 16th Century, and your mathematician is applying skills to the use of instruments like this. It is curved because it sits on the end of the gun. There is a scale for the elevation, and there are other ways of doing it. So the military art, the art of war, is very much what the mathematician provides to the Prince.

There is a very interesting instrument, which I am sure would have delighted Cosimo. First of all it looks like a gunner's calliper, that is to say for measuring the size of the shot, but the maker has been able to incorporate lots of little clever features into it. He has a quadrant. There is a plumbline which allows you to measure altitude. He has a clinometer scale, which allows you measure the inclination of the gun. He has a little gimble magnetic compass, which is actually an equinoctial sundial - you can adjust the gnomon for the latitude to find the time. Eventually, when you use it for what you think it is obviously for, that is to say measuring the size of the shot, there are two points that you put between the external diameter of the shot, and then you read the scale, the size. Actually, you don't read the size, because it says FERR, and there are four different scales on the different sides of the arm for different materials of shot. You have one for iron, you have got one for stone, and one for lead. So you are reading directly the weight of the shot depending on the material of the cannon ball, they would say, shot. So this is very much part of the gunners' art. It is a mathematical instrument, within the programme of the geometers.

There is an utterly wonderful and brilliantly ambiguous instrument. It looks like a surveying instrument I suppose. You would think yhere are sights on the arms, and they move around on a disc, and the disc has a degree scale - it is actually a scale divided according to the winds of the Mediterranean, which is typical of the Italian instruments in the 16thCentury, how they divided the horizon into the winds of the Mediterranean. You would use the sights then just like an ordinary theodolite for measuring bearings, as you might expect, but why are the arms a funny shape? Well, they are a funny shape because it is also a gunner's calliper. There are points for measuring the size of the shot, and there are scales, just as on the arm, for shot scales, for the weight of the scale. So it is an amazingly and wonderfully ambiguous thing, which shows the eclectic scope of mathematics, and, more, there is, on top, a clinometer scale and a sighting scale for gunnery. I had the privilege, with my gloves on, of actually playing with these things and

seeing how they work. If you close it up, there are little curved feet underneath, and the whole thing actually sits on the gun, so that you can elevate the gun and use the clinometer scale to elevate it to the right. It is just extraordinary, it is a brilliant thing, but, you know, at some point, you have to step back and say "Do I believe this?" In the kind of mess and noise and mud and confusion and smoke of the battle, is the gunner going to bring this out? Well, of course it is very hard to believe that. I don't believe that. This is for showing off at court. This is for cutting a good figure. It is a rhetorical instrument in many respects.

That rhetoric of instruments is beautifully shown, I think, in an instrument called the Radio Latino, which is in the collection. It has a sliding piece and pivots. That thing slides up and down on the rod. You can do all sorts of things with this! They loved universal instruments that did everything. You can measure the height of the Sun, you can actually find the time, you can measure the inclination of the gun, you can measure the bore, you can use it like a military surveyor, measuring or laying out a typical polygonal fortress. They were becoming popular for defence - the defensive side of mathematics was a geometrical discipline. You can use if for measuring angles and so on as a surveyor. So it is very much a military instrument.

There are illustrations from a treatise by Egnazio Danti - remember the man who started the room in the room - and he shows you all the things you can do with it. It is actually an edited treatise by Danti. When you finish doing your work for the day, you close it up, it becomes a straight rod, and you wear it in a scabbard on your belt. It is extraordinary! The mathematician, when he arrives at his work, he draws his instrument, as though it were a sword. So even the gestural content is rhetorical. The mathematician is placed in this very worldly context in the service of the Prince, and that is of course where this collection lives.

There are too many of these things to talk about, but there is a triangulation instrument, a range finder we would say. It looks like a surveying instrument or perhaps a sector, but here, again, you have these things you are accustomed to seeing now, these levels or clinometers for the gun. The way they used this instrument is a slightly different one, because there are lots of triangulation instruments. The story here is incredible. These guys, this cohort, whatever, just got off a ship, they are advancing on this curiously undefended fort. You have these big guns, but, you know, there is all the estuary in between - you cannot get to them. Time is short, they are going to get there any time, you haven't time for ranging shots and so on, you pull out your mathematical instrument that is going to solve the problem for you. You take a baseline, which you can measure, you make that scale equal to the baseline, you take two sights. It is an interesting diagram because it shows the two events, simultaneously, but in fact it is sequential, and then you end up with a triangle that is similar to the triangle on the ground. So you can scale up. Your first shot knocks them out, and the Prince is happy, and mathematics has triumphed in the service of the Prince! That is the story. There are lots of these triangulation instruments, one by Lanci, in the collection.

I will move quickly over some of the really rather extravagant instruments - a Schissler quadrant, a theodolite: surveying is very much part of the story here. There is an apparently innocuous looking instrument - you might think non-military surveying instrument, until you look at the scale. The scale around the edge has got degrees, fair enough, but it also has polygons. It can be used for laying out polygons in the field for whatever number of sides you need because of the polygonal fortresses which are common in the 16th Century.

One of the nice things about working in a collection like this of course is, because it is a natural collection, you have the manuscript record. You may remember, if you have been to Florence, that there is an extraordinary armillary sphere by Antonio Santucci. This fills the room - it is just crazy, so you will remember it - you cannot miss it! Antonio Santucci left an extraordinarily beautiful manuscript treatise on the various diverse mathematical instruments - I haven't been fibbing, these are mathematical instruments in the 16th Century, instrumenta mathematica, which are kept in the Guardaroba of the Grand Duke of Tuscany. So not only do we have the instruments, we have this treatise that Santucci wrote in order to explain their use. That is very useful, because sometimes, for instance, a particular instrument, which

looks like a level, according to Santucci, is also used for altitude work.

One instrument by Bianchini is a surveying instrument, but it has polygons for laying out fortresses, and Santucci tells us everything we can do about it. It is also a triangulation instrument, with an additional arm, according to the manuscript. There is an extraordinary surveying instrument by Lanci, which is also used for drawing in perspectives. There is also a German instrument which came to the collection a little bit later in the 17th Century. I don't think that is really Cosimo's style.

We have seen a lot about what mathematics is. There are drawing instruments, I admit, there are sets of drawing instruments, which we would recognise as a mathematical instrument set - one is by Schissler from the period - but we have had to expand our expectations and our scope enormously in order to accommodate the range of instruments that you find in the Guardaroba. The mathematical arts, the mathematical instruments of the period, are applied to solving a range of problems, but they are not scientific in our sense. We have talked about the expansive side. There is a limit to what these things can do as well. They do not discover new truths about the natural world. They are not scientific instruments, they are not for investigative purposes, they are not for discovering things, they do not teach you anything you do not know about the natural world before you began, they are not for uncovering causes, which is, in the 16th Century, the business of a separate discipline called Natural Philosophy. These instruments do not do that. They deal this range of practical problems. They are held in high esteem - they are in the Guardaroba of the Prince - but they do not engage with Natural Philosophy.

That is true of the early work of Galileo. I have a picture of the printed title page from Galileo's Geometrical and Military Compass. So when he is a mathematician, when he is a proper mathematician in Padua, he is doing this kind of thing. He produces a sector, which is in the collection, in the Medici Collection, and it is used for laying out fortifications, it is used for gunnery, for shot scales, and so on. Galileo is a mathematician in exactly this mould in his early work, before he achieves his ambition to become a natural philosopher in the service of Cosimo.

Very briefly, regarding what happens to Galileo later, I just want to say something else. There is a real British dimension. There are English instruments. The finest collection of Elizabethan English mathematical instruments is in Florence. The collection is not only the finest, but also the only natural collection of early English instruments has survived in Florence. The individual who put it together was Sir Robert Dudley, the navigator, son of Robert Dudley, Earl of Leicester, famous as you will know for being a sometime favourite of Elizabeth I. Sir Robert Dudley, the illegitimate son - that was the story of Robert Dudley's life, trying to establish exactly what his status was in relation to the Earl of Leicester - but Dudley's first contact with the Medici comes in 1609, and he lives all of the latter part of his life sort of in exile in Florence, but he has a lot of instruments with him, and it gives the collection a wonderful English/British flavour, or London flavour if you like.

There is an extraordinary collection of astrolabes, one by Thomas Gemini, the first mathematical instrument maker with a shop in London. A wonderful name, Thomas Gemini - how could you get a better name?! Of course he wasn't called Thomas Gemini at all. When he came as an immigrant from Flanders to London, he, as we would say, branded himself. It is not such a modern idea, you know. He is actually called Thomas...something Flemish I can't even remember for the moment! There is no point, in London, being called Thomas something Flemish I can't remember, so he calls himself Gemini, and it works! It is such a cool business strategy. You would think it is a 20th Century move. Not a bit of it! It is a 16th Century move. Thomas Gemini makes this instrument, this beautiful quadrant, and you can recognise some of the features, the sine, trigonometrical table and so on.

The British stuff moves the collection into surveying and into navigation, but in a very innovative way. We have instruments in Florence, British instruments, London instruments, that do not exist anywhere else. There is also the only example of a nautical hemisphere, and it is in Florence, made by Whitwell. It is for

calculating, solving the sorts of spherical triangles you get in navigation. There is "L'Arcano del Mare", the book by Dudley, where he explains something of his techniques - "The Secrets of the Sea" - some of his techniques for navigation and for shipbuilding and his charts and so on. Nineteen of these English instruments are in the Museum of the History of Science.

So the other lesson then is the rise of London. We have seen Louvain instruments, we have seen instruments from Italy, we have seen instruments from Nuremburg, and now, the beginnings of the London trade in instrument making are represented, you might think strangely, but gloriously, in Florence.

I just want to end with what we have not talked about - Galileo's telescopes. The original telescopes are in Florence, representing a new departure for the use and competence and functionality of instruments. Galileo is a mathematician. When he thinks that the telescope has a use, when he thinks there might be an opportunity here - and Galileo was a great opportunist - what is the opportunity he sees? A military instrument of course; he tries to sell it to the Senate of Venice as an instrument that would give you advantage over your enemies - you can see them before they will see you, that kind of thing! It is only afterwards that he thinks, well, maybe there is some astronomical interest here - and the rest, you know! But that is a new role for instrumentation: discovery. That is represented naturally in the collection.

The other new role for instruments comes with the instruments of the Accademia del Cimento. That is the instrumentation coming to be used investigatively within experimental natural philosophy in the mid-17thCentury. I have not time to say much about that, but it happens naturally in a natural collection. So that story of the progression, of a progression with the development from mathematical instruments to instruments of observation, optical instruments, instruments that experiment, instruments of natural philosophy, is naturally played out in a collection which is allowed to take its natural course, to come to being in a context we know and to have been preserved, partly through neglect, partly deliberately, and come down to us today as a unique example of instrumentation from the 16th and 17th Centuries.