Activity inspired by Medieval Observers with Tube

Activity inspired by Medieval Observers and Tubes
Elizabeth Cavicchi

Abstract: As a scientific apparatus, a hollow tube can be used to demonstrate and model many properties of the physical world. In medieval times, tubes were an instrument of science and teaching in optics, astronomy and acoustics. By sighting through a tube held both near and away from the eye, eleventh century experimenter Ibn al-Haytham argued that light travels only in straight lines. In tenth century Europe, Gerbert of Aurillac's students set up a tube to view the North Star all night. Viewing the sky by additional tubes showed them about the seasons. They also made sounds with an early tube-based organ. Twelfth century illustrators show a medieval person looking through a tube to tell time at night. These stories invite you to explore with tubes. Play and imagine; experiment and create. What do you notice, see, hear and wonder about?

Introduction

People have always been curious about what and how we see and hear. In medieval times, observers invented many ways of using a hollow tube to help them notice science relationships with light, astronomy, sound and music. A tube can be a guide, a resonator, a sighting aid, or a musical instrument. A tube with nothing inside can assist someone to see or understand something that might otherwise be missed. Early accounts of activities with tubes illustrate how the simplicity of a tube led to a more complete perception and understanding of the physical world.

This article invites you – students and teachers – to try out looking and exploring with tubes. What do you see? What do you hear? Take on the perspective of people who might have looked through and listened to tubes. Stretch your imagination. What else can you do with tubes?

A Tube for Sighting in Medieval Studies of Islamic Scientists

Tubes were not always what someone used to view far-off sky, mountains or buildings. Greeks and Romans of the classical period who were surveying a piece of land or watching the night sky might employ a sighting rod or dioptra. Sticking out at right angles from each end of this rod was a flat extension, with a hole punched through it. To observe with it involved aligning those two holes with whatever someone wanted to see, and then peeping through both holes. The rod might be mounted on a support or pivot having angle markings to use in measuring its position (Figure 1 A top).[1] This sort of viewing through paired holes in "vanes" mounted on a bar or "alidade" was a component of the astrolabe (Figure 1A), and of other instruments used by astronomers even after the telescope's invention early in the seventeenth century.[2]

Tubes become more evident in the manuscript records that come down to us from medieval times. For astronomical observing sometimes a tube replaced the dioptra, for example on some instruments at the renowned mid-thirteenth century Maragheh observatory in Iran as well as among surviving or recorded Chinese instruments dating from the Mongol and Ming dynasties.[3] Mention of optical demonstrations involving tubes occurs much earlier, among the productive era of science produced in the Islamic world during the ninth through eleventh centuries.[4]

---

[1] LEWIS (2001), p. 51-108. Aristotle described looking through a tube to see far; he also wrote that someone sitting in the bottom of a deep well can see stars in the daytime, EISLER (1949), p. 313.
[2] EVANS (1998), pp. 141-161.
[3] JOHNSON (1940), p. 38; EISLER (1949), p. 313; NEEDHAM (1974), p. 75; DEANE (1994), p. 132.
[4] KHEIRANDISH (2009).

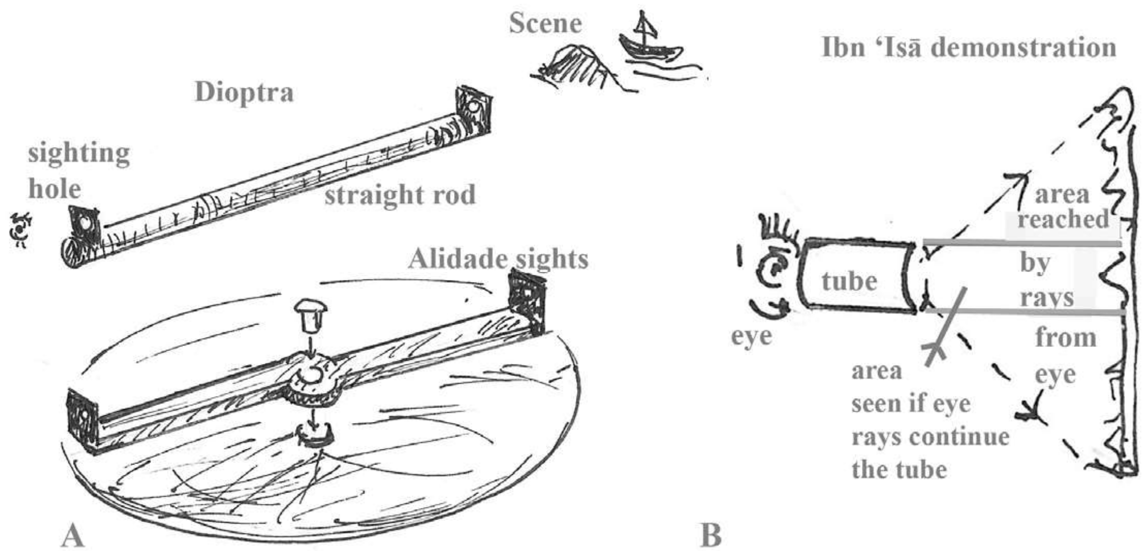


Figure 1 A: Top: a dioptra with two upright sighting holes on a rod; Bottom: the sighting vanes on the alidade of an astrolabe. **B:** Diagram of the area that will be seen if the rays of an eye fan out after passing through a short tube, in Ibn 'Īsā's demonstration.

The ninth century work of Ibn 'Īsā on optics is a pioneering example from science history where part of the writing takes the form of presenting an observation to be tried with an instrument -- the tube. A short copper tube would be placed over one eye. Looking through it at something, he expected the view of that object would be wider than what would correspond to continuing the tube's diameter directly onto the object (Figure 1 B). Ibn 'Īsā came to have this expectation on the basis of the prevailing interpretation that vision occurs by means of rays that the eye sends into the air on paths that widen out like a cone to reach the things we see.[5] While the tube's opaque wall would block these supposed eye's rays, once those rays passed beyond its barrier they would then be free to spread outward. The eye would see whatever the eye's expanding rays fell upon.

[5]For the translated text of Ibn 'Īsā's tube demonstration, see KHEIRANDISH (2009), pp. 79-83; 96-97.

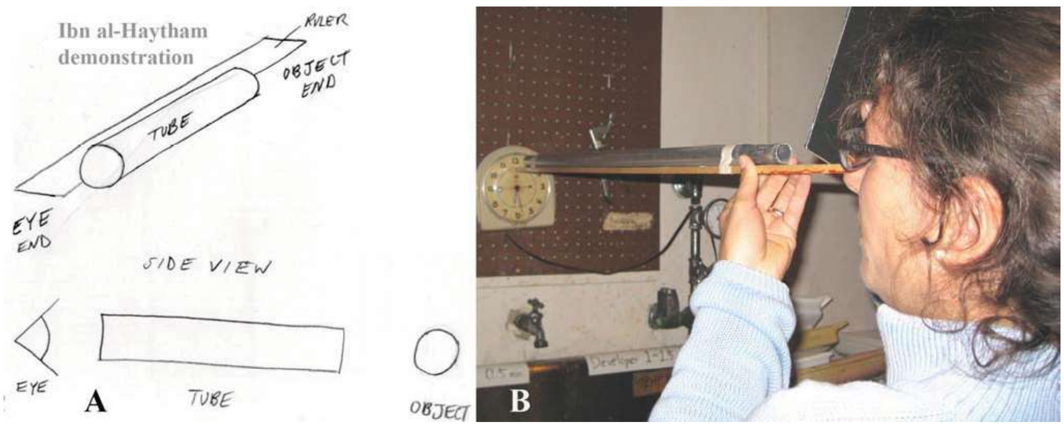


Figure 2 A: Diagram of a tube positioned on a ruler between the eye and object; drawing by Cecily Lopes. **B:** Photo of the tube and ruler as used to view a clock.

A hollow tube figured in the ground-breaking experimental demonstrations that Ibn al-Haytham developed in the eleventh century in support of the opposing premise: that rays travel from an object to the eye. As part of the analysis that he constructed in the course of arguing for this alternative understanding of vision, Ibn al-Haytham showed that vision perceives only by means of straight lines between object and eye. He described the tube carefully: it should be a very straight cylinder whose circular ends were of the size to fit over a person's eye. In one demonstration, he rested the tube on a longer ruler whose far end touched the object (Figure 2 A). First, with the tube's end right at the eye (like Ibn 'Īsā) he looked through; then with the tube put toward the object, he still saw the same portion of the object through the tube (Figure 2 B). In each case, when he put a barrier put over half the tube's far end, it blocked him from seeing half the object. Ibn al-Haytham argued that if light did not take straight lines, it could get to the eye by curving in the open space between eye and tube, and around the barrier.[6]

[6]For the translated text, see IBN AL-HAYTHAM (1989), Bk. 1, Ch. 2, pp. 7-8; KHEIRANDISH (2009), pp. 99-101.

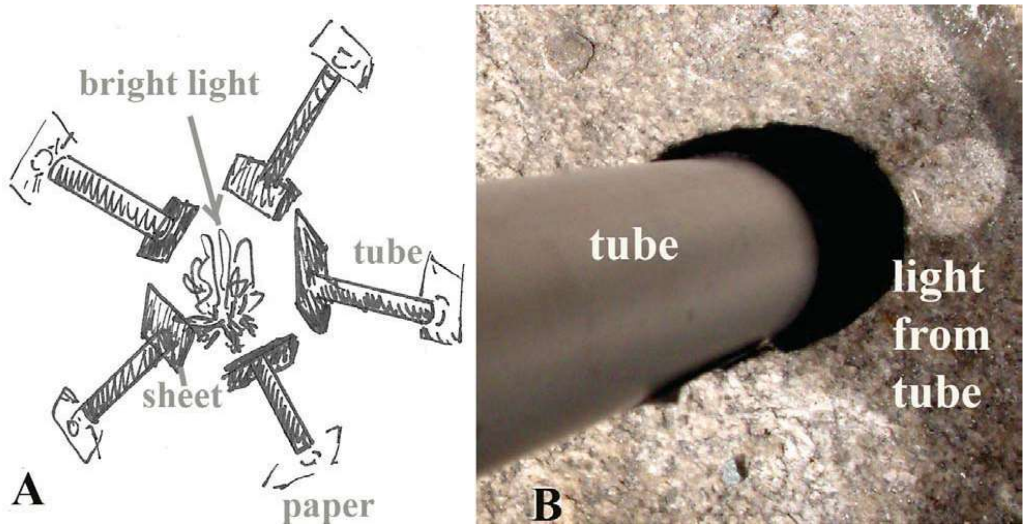


Figure 3 A: Diagram showing a bright light and five different positions of a tube passing through a hole in a sheet; white sheet at its far end shows a bright dot of light. **B:** Photo of a tube and the dot of light produced at the end that is away from the light source.

To show how light comes off something bright like a fire, Ibn al-Haytham used a tube in a different way, without looking through it. He fitted the tube into a hole in a copper sheet. When he held the sheet up to the bright fire, no light got to the other side of the sheet, except what went through the tube (Figure 3). Beyond the far end of the tube, he put a white board, instead of his eye. Whatever light entered the tube might show up on that board, where he looked at it while standing to the side. The white board was a viewing screen that made it safe to observe very bright light without directly affecting the human eye. The firelight that Ibn al-Haytham saw on the board had only gotten there by going through the tube, on a straight line (Figure 3 B). If he tipped the tube and its blocking sheet in different ways, firelight still came through the tube to its far end. If he raised, lowered, or moved the flame, again some of its light passed through the tube. With the help of these observations, he argued that light travels "in every straight line" coming from a bright object.[7] The tube was a tool for identifying the paths that light takes, and at the same time its straight form served as a model for those same paths.

[7]For the translated text, see IBN AL-HAYTHAM (1989), Bk. 1, Ch. 3, pp .18-20. EISLER reports an astronomical use at the Maragheh observatory for sunlight passing through a tube, EISLER (1949), p. 313.

The straight tube aided these observers in their efforts to understand how we see, and how light goes from place to place. Since the tube worked both for looking through and for letting light through, both Ibn ʻĪsā and Ibn al-Haytham used it, even though each came to a different, contrary, understanding of how the eye sees things. Light and looking are interrelated in such a way that looking through a straight tube shows us something, unlike a tube that is bent, curved or some other shape.

A Medieval Teacher and some Tubes

In the late tenth century, between the lives of Ibn ʻĪsā and Ibn al-Haytham, a teacher at the cathedral school in Reims, France had his students use tubes for viewing the night sky and learning about sound. At that time, not much about science, math or music was taught in Europe, where the schools were typically part of monasteries. This teacher, Gerbert, was a son of peasants who lived near one of those schools in Aurillac, France. Somehow he was given the special opportunity to study there, even though in those days peasants had no access to education. He was so interested in learning more that the abbot who directed that school arranged for Gerbert to travel to Spain to study. In Spain, Gerbert learned math and science from books and instruments that originated in the Islamic world, where more innovation was going on in these scholarly areas.[8]

When Gerbert returned to France to teach, he introduced his students to the new knowledge of math, astronomy and music that he learned during his travels. Gerbert's lessons made a fresh beginning for math and science in the part of the medieval Europe where people communicated in Latin. Unlike the book-based trivium that formed the basis of learning in the European monasteries, Gerbert's teaching put students into the experience of actually doing whatever they were learning about instead of just copying out of handwritten books by hand. If the students were learning astronomy, he had them go outside and look at the stars; if it was math, they did calculations; with music, they made sounds and listened. Gerbert provided his students with instruments for active learning, tools that students could use in looking, calculating, and listening. One former student wrote that Gerbert expended a considerable "quantity of sweat" in making these instructional instruments![9]

---

[8]LATTIN (1951) is a book about Gerbert written for young readers. Also see DARLINGTON (1949), p.459-60; CAVICCHI this volume.

[9]RICHER (1930), v. 2, pt. 1, p. 58-59; DARLINGTON (1949), p. 467.

Gerbert interpreted the earth and the heavens around the earth as spherical. To help his students think about spherical relationships among the earth and stars, he made a wood globe to stand for the earth and set up wire hoops that could be moved around the globe's outside, to show what stars might be doing as they rise and set from the view of someone on earth. To help his students apply those relationships while they looked at the night sky outside, Gerbert made a sighting instrument. It had six tubes mounted so as to point in different directions. The tubes were held within a spherical support that had constellations patterned on it in wire. To use this instrument, students had to first set the sphere up so when they looked through one particular tube, they viewed the North Star. Now keeping the sphere in that same place, when they looked through each of the other tubes, it pointed them toward the place in the sky of Arctic circle, or the equinox circle, or the circles that show the limits of the summer or winter sky.[10]
Almost a planetarium "in reverse," this tube sighting sphere was an early use of a model for illustrating the invariant properties of the physical world. At that time, understanding the invariants of the night sky was crucial to everyday survival. People needed to know when winter was coming to prepare for its hardships; by following where the stars were every night, they could predict winter's approach. But unaided, the human eye cannot discern the small changes from day to day. Gerbert's instrument gave students aid in perceiving the subtle motions of stars, and how these motions related to the calendar and seasons.

This model was unrelenting in showing that not everything behaves the same way; if the student didn't aim the first tube in the device at the North Star, but instead at some other star, then all the other tubes would be pointing in the wrong directions for identifying those reference circles in the sky. In a letter to one of his students, Gerbert described how to be sure that the tube was aimed at the North Star:

> If you doubt that this is the polestar [North Star], station one tube in such a position that it does not move during the whole night and look toward that star which you believe to be the polestar. If it is the polestar, you will be able to see it the whole of the night; if any other star, it will soon not be visible through the tube because it will have changed its position.[11]

---

[10] RICHER (1930), v. 2, pt. 1, para. 50-53, p. 62-63; DARLINGTON (1949), p. 467-470; GERBERT, Letter 2, in LATTIN (1961), p. 36-37; EISLER (1949), p. 321.

[11] DARLINGTON (1949), p. 469-470; GERBERT, Letter 2, in LATTIN (1961), p. 36-37.

We learn some of Gerbert's contributions via his correspondence with his students. A former student, Constantine, who had started as a new teacher, wanted to make for his own students a spherical device with sighting tubes like Gerbert's. In a letter to Constantine, Gerbert advised him to choose tubes of the same length, around one foot long, for the astronomy project, instead of tubes of all different lengths that are "like organ pipes".[12]

Constantine later became so skilled as a teacher, that Gerbert recommended that others go to him to learn music with the organ.[13] At that time, learning music was part of learning math; the lengths of the tubes in the organ have mathematical relationships. Gerbert wrote a mathematical work on the organ in which he discussed the measurements of the different lengths of pipes.[14] These tubes were probably made of brass.[15]

It is surprising – given the key role of the organ in the modern church – that in medieval times, it was not even accepted as a church instrument. In later centuries, organs came to be great instruments of church music, having hundreds, thousands, or even tens of thousands of tubes whose lengths varied from under a foot to thirty-two feet or more. There were instruments having multiple tubes in antiquity; organs sound in David's psalm celebrating musical instruments for offering praise.[16] The organs of classical Greece had several pipes and a keyboard for selecting which pipes would sound. It took work from a person, or another source such as a windmill, to operate an action of air piston and water chamber that sent air into the instrument's sounding pipes.[17] However, in early medieval times, organs were uncommon in Europe; their tubes' haunting sounds made them unwelcome in churches where some feared hearing ghosts or the devil in the breathy tones.

Since the organ was more accepted and developed in the Islamic society in those days, perhaps Gerbert learned to make and use organs during his student years in Spain where he had the opportunity to learn from other cultures. Later in life while he was directing a monastery

[12]DARLINGTON (1949), p. 469-470; GERBERT, Letter 2, in LATTIN (1961), p. 36-37; FLUSCHE (1994), p. 123.

[13]FLUSCHE (1994), p. 126.

[14]FLUSCHE (1994), p. 142-144.

[15]WARMAN (1903), p. 39.

[16]Psalm 150, 4. The instrument is variously rendered as organ, flute or pipe in different English translations of this verse; organ appears in the 1611 King James version.

[17]HERO (1971), sec. 76-66, p. 105-109; WARMAN (1903), p. 43-44; FARMER (1931).

in Bobbio, Italy, Gerbert probably built organs and taught students to work with organs as a way to understand sound and music. Afterward, he returned to the school in Reims, France, but was unable to retrieve the hand-made organs. His own teachers in Aurillac wrote to him repeatedly, asking about these organs that were left in Italy. Wars and politics made it impossible for Gerbert either to transport the organs to France where the monks could learn to play them at school, or to send a French student to Italy for practice with the instrument there.[18]

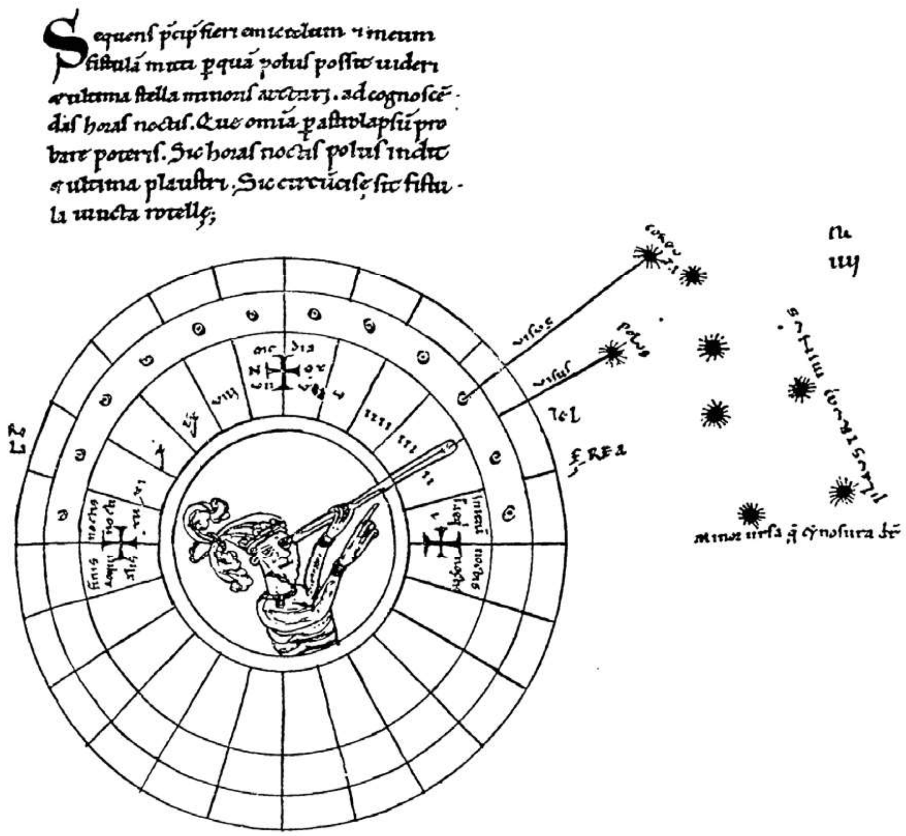
With tubes in their hands, Gerbert's students could try out something for themselves. They did not just take someone else's words for what they had to know. The students were the ones working out how to position the tubes to see something in the sky. The students were also making sounds with tubes, listening to how one sound related to another. And, through what they learned while doing activities with tubes and other instruments, Gerbert's students became so thoughtful and skilled that, like Constantine, they became the teachers and leaders of people in coming times.

By noticing what was going on with the actual tubes, Gerbert's students were learning science. From the different orientations of same-sized tubes in Gerbert's sphere mounting, the students could tell how the observed parts of the heavens related to each other and to where they stood on earth. They were using a model to help them notice what changes from night to night in the sky. From the different lengths of tubes in the organ, the students could uncover how a sound's pitch relates to a sounding tube's length. By having many tubes in a single instrument, the students were encouraged to compare and contrast the properties of those tubes, whether for astronomy or music. Tubes played many roles in doing and learning science: tubes aided people in seeking out physical invariants of light, stars and sound; tubes enabled one person to reproduce someone else's experiment; tubes were part of the models that people formed to interpret what they observed with tubes.

Drawings from Old Manuscripts of Medieval Observers with Tubes

None of Gerbert's teaching instruments with tubes exists today. However, some of Gerbert's writings on science and math were preserved in books of manuscripts that people copied by hand. Even though he came from a peasant family and was not noble, Gerbert's

[18] FARMER (1931), p. 155-157; FLUSCHE (1994), p. 125-129.



work gained importance in the eyes of others when he became Pope Sylvester II during the final years of his life.

A medieval person looks through a tube at the sky in a few illustrations to hand-written books of the twelfth century. The two drawings that are reproduced below were made by artists who may have never looked through a tube themselves. Although these artists' drawings may be exaggerated and inaccurate, they help us imagine what it was like for a medieval person to look through a tube at stars.

Figure 4. MS Chartres no 173, originally at Médiathèque L'Apostrophe, Chartres, France, reproduced with permission.

One drawing of a tube (Figure 4) was part of a manuscript that was kept in a library in Chartres, France for nearly 800 years until it was destroyed during World War II bombings in 1944. Before the war, a scholar who was studying that same manuscript took a photograph of its illustration showing a medieval man viewing the North Star through a tube. His photograph reproduced below reminds us of how

Gerbert, his students and their students observed and understood the stars, and of how human works are vulnerable to loss.[19]

Notice how a line goes from the North Star (Polaris) through the tube to the man's eye. The writing above the drawing indicates that he is using tube observations to find the hours of the night.[20] This observation is different from what Gerbert's students did when they used the sphere with the six tubes mounted through it. This drawing puts the man within a circle whose outer rings are divided in twenty-four parts, like the twenty-four hours of a day and its night. The tube is oriented at the North Star, which is located above the horizon about a third of the way up toward the highest part of the sky. The North Star stays there all night, while the other stars travel along circles around it. Looking up all night at the stars, they seem to move like a great clock dial in the sky.

Mechanical geared clocks would not be available until far in the future. Navigators at sea, astronomers and others had to know the time at night. So from antiquity, people have carefully watched the stars' paths from night to night over one year and over many years. Putting these observations together, they worked out patterns in where the stars were at different times, and used these patterns to design and mark instruments. To use one of these instruments, it had to be oriented so someone could see the North Star along its tube or dioptra, then after noticing where the other stars were, find the place on the instrument's dial corresponding to them, and read off the present time of night from its markings. The orientation of the tube or dioptra was a basis for finding the angle to whatever fell within its view.

A tube aimed at the North Star appears in another twelfth century manuscript which still survives among the medieval volumes that were created and preserved by the Benedictine monastery of Mont-Saint-Michel, France (Figure 5). This illustration is found in a book of writings on science and technology that includes a text by Gerbert.[21] The book's beautiful artwork lets us peep into medieval life. We see the old-style of curly hairdos, tight stockings and loose costume along with the comedy of an observer's body pretzeled upside-down with a tube. This illustrator lets us *feel* a medieval observer's plight in trying to watch the bigger world and make sense of it.

---

[19]This manuscript contained a work by Gerbert on the astrolabe. MICHEL (1954), p. 176-177; POULLE (1985), p. 607, n. 19.

[20]Partial translation of the text: "According to this method, one makes a half-circle, and within it one fastens a tube by which one might see the pole and the last star of Ursa Minor, to know the hours of the night…" MICHEL (1954), p. 176.

[21]LATTIN (1932), p. 62.

While showing us what the harried observer went through, this illustrator is less precise about how someone might use a tube while watching stars at night. Unlike the drawing in Figure 1 which shows the North Star about where someone in France might see it, in this one the North Star is directly overhead where no one then had seen it. And the circle around the man, which might stand for the instrument's dial, has no markings. Even with these exaggerations, the drawing adds something new for us to puzzle about. There is a sightline parallel to the tube, going to another star.[22] How might the observer have gotten an eye under that sightline's lower end?

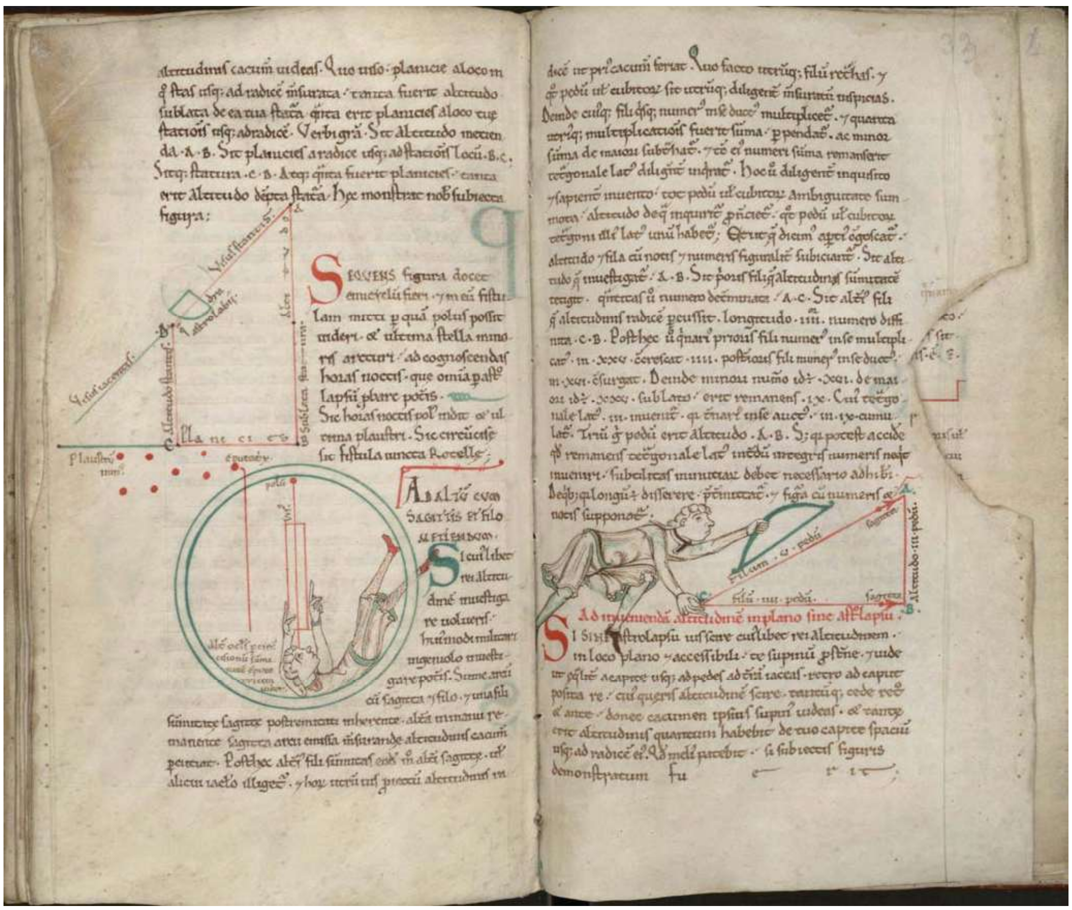


Figure 5. Ms 235 fol.32v, Ville d'Avranches, Avranches, France; reproduced with permission.

[22]POULLE (1985) p. 609-610. Like Ibn ʿĪsā, this artist probably believed that the eye sees by sending a beam out to the object.

One of Gerbert's contemporaries reported that while Gerbert was in Magdeburg, Germany to tutor the seventeen-year old Emperor Otto III, he observed the North Star with a tube and used it to tell the time at night.[23] Gerbert was perhaps the first European to make time observations while sighting the star through a tube, rather than by a simple dioptra. We do not know if the tube instrument that Gerbert constructed in Germany was similar to the tubes illustrated in these two drawings by artists of a later time.

Let these stories and drawings open a window for you to the people and science of medieval times. They are beginnings for your imagination and curiosity, not something to copy directly. Invent your own ways of doing something with tubes. Put yourself and a tube in a medieval person's world. Look and listen.

Exploring Tubes!

Like Gerbert's students who did whatever they were learning about, now I invite you to play and explore with tubes. Playing and exploring is a wonderful way to learn. Let whatever you notice or do with tubes become a new curiosity for you. Have fun!

What surprises you? How can you change the tube or how you use it; does something different happen then? What tube activities might you invent to try with your friends or other people?[24] What might you try next?

Collect tubes of different lengths, shapes, widths, and materials. Some tubes you might find include: cardboard mailing tubes; brass or aluminum hobby tubes; soda straws; coffee stirring straws; plastic tubes; plastic pipes; clear plastic tubes. Take a sheet of paper and roll it into a tube. If you make your own tube out of paper, it can be as small or wide or long as you like. You can tape tubes together to make them longer.

Play around with looking through different tubes. What do you see? How might you show your friend something that you saw with a tube? Do others see something different?

Can you sight something that is moving? What happens when you

[23] POULLE (1985) p. 607-610; FLUSCHE (1994), p. 56-57.
[24] The activities of four-year-old children in exploring with clear tubes and water are described in HAWKINS (1969).

watch it through the tube? Imagine looking through a tube for a whole night at a star, like the medieval person; how would you get ready to do that? What do you see at night?

What sounds can you make with tubes? What changes how a tube sounds? Combine tubes, sounds, and other materials. Create music with tubes.

As you explore, look, observe, and make sounds with tubes, what differences and contrasts do you notice between the tubes or what is going on with them? Describe what you see, hear, feel and do. Is there anything related to the tubes that you can measure and compare?

Imagine the students who used tubes in medieval times for looking at the sky, understanding light, and making sound. What might they do, notice and wonder about? What can you find out by trying to do what they did? Continue their story with something you do and observe.

There is always more with tubes that you can explore and try. You might take photos, write notes, or make drawings of what you do and discover; this will become your own story. Every person's story is different, and everyone's story is related!

The photos below (Figures 6-9) might inspire your own explorations with tubes! What will you try, see, hear, create and discover with tubes?

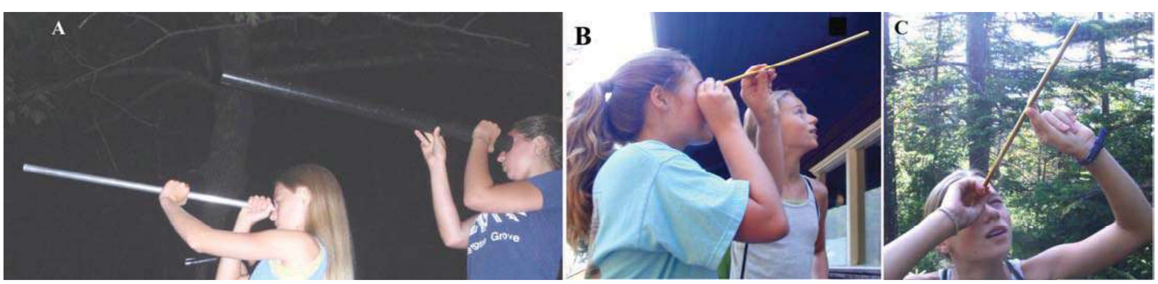


Figure 6: Three sisters looked through tubes. **A:** On a dark summer night, they viewed the moon by tipping the tubes just a little above level. **B:** One morning later, the moon was already high when they first looked at it through a narrow tube. **C:** Later on it was even higher.

Figure 7 A and B: To see the stars overhead, the sisters leaned very far back, and even put their heads on a table, almost like the medieval person in the drawing. **C**: The sisters made sounds with tubes by blowing over the tubes. **D:** They tapped tubes with their hands and listened.

Figure 8 A: The sisters tapped tubes and danced. **B:** They made original music and creative rhythms by clanging and blowing tubes. **C:** One girl dropped a small tube through a long one. **D:** She rolled and clanged tubes on the floor.

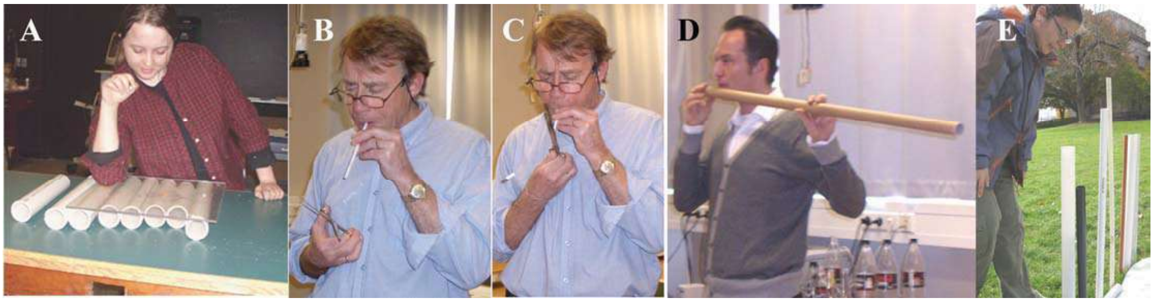


Figure 9 A: A college student lined up several tubes of the same size so they rolled together to carry a weight. **B and C:** A musician made tones by blowing into a soda straw while he cut it with scissors. **D:** A teacher blew into a tube sideways. **E:** A student set tubes upright outdoors to watch their shadows.

Follow these safety issues when you use tubes:
Never let your eye look through a tube at the sun or at a very bright light. Remember that Ibn al-Haytham was careful to let bright light pass through the tube onto a solid object. You might try holding a tube so that bright light goes through it onto the floor, but never put it toward someone's eye.
Never look into a tube without first checking that its inside is clean and empty. To make a tube safer for looking through, tape a clear cover over one end. Never drop something into a tube unless you are sure it is safe for the object to fall out.

Do not experiment with tubes and flame unless you are being guided by a person who has experience with flame.

When we explore tubes, we are being creative while doing something – like looking, making sounds, constructing and arranging tubes, and wondering about what happens. We might see, do, or hear something for our own first time. We are beginning adventures in learning about the world and ourselves, adventures that we share with the students and scientists of medieval times.[25]

Acknowledgements
Costantino Sigismondi introduced me to the story of Gerbert and encouraged my thoughts about a teaching activity related to Gerbert's tubes. Elaheh

[25]For examples of exploration as a way of teaching and learning, see DUCKWORTH (2001); DUCKWORTH (2006);
CAVICCHI (2008); CAVICCHI (2009).

Kheirandish introduced me to the optical writings of medieval Islamic science and invited me to try these experiments with our students. James Bales and others at the Edgerton Center at MIT support a welcoming setting for my historical experimental teaching. John Peter Collett, the Forum for University History, and the School Laboratory at the Department of Physics of the University of Oslo, Norway sponsored my sound exploring workshop with tubes and other materials. The teaching of Eleanor Duckworth inspires my efforts to open up experiences of exploration for learners. Peter Heering, Alythea McKinney, Klaus Staubermann, Ryan Tweney express history, science and materials in their teaching and research. Alva Couch sustains my hopes for exploring. I thank my students in tube explorations: Emanuela Fabbri, Mingwei Gu, Julia Kingsdale, Cecily Lopes, Ana Malagon, Marco Santambrogio and participants in the Sound Workshop at Skolelaboratoriet, University of Oslo. My heartfelt joy with the three sisters: Violet, Elise and Julia Cavicchi! This work honors the memory of my longtime teacher, Philip Morrison.

Bibliography

ELIZABETH CAVICCHI, "Opening Possibilities in Experimental Science and its History: Critical Explorations with Pendulums and Singing Tubes", *Interchange* 39 (2008), pp. 415-442.

ELIZABETH CAVICCHI, SON-MEY CHIU, FIONA HUGHES-MCDONNELL, "Introductory Paper on Critical Explorations in Teaching Art, Science and Teacher Education", *New Educator* 5 (2009), 189-204; Open Access Link: http://www1.ccny.cuny.edu/prospective/education/theneweducator/volume5_3.cfm

ELIZABETH CAVICCHI, "Reflections on the Teaching of Gerbert of Aurillac", this volume.

OSCAR G. DARLINGTON, "Gerbert, the Teacher", *The American Historical Review*, Vol. 52, No. 3 (Apr., 1947), pp. 456-476.

THATCHER DEANE, "Instruments and Observation at the Imperial Astronomical Bureau during the Ming Dynasty", *Osiris* 9 (1994), pp. 126-140.

ELEANOR DUCKWORTH (ed.), *"Tell me more": Listening to learners explain*, Teacher's College Press, New York, 2001.

ELEANOR DUCKWORTH, *"The having of wonderful ideas" and other essays on teaching and learning,* Teacher's College Press, New York, 1986/2006.

ROBERT EISLER, "The polar sighting tube", *Archives Internationales d'Histoire des Sciences* 6 (1949), pp. 312-332.

JAMES EVANS, *The History and Practice of Ancient Astronomy*, Oxford University Press, New York, 1998.

HENRY GEORGE FARMER, *The Organ of the Ancients*, W. Reeves, London, 1931.
ANNE MARIE FLUSCHE, "*Organa Doctorum*: Gerbert of Aurillac, Organbuilder?", Unpublished doctoral dissertation, Rice University, Houstin TX, 1994.
GERBERT, *The Letters of Gerbert*, HARRIETT PRATT LATTIN, trans. and ed., Columbia University Press, New York, 1961.
HERO OF ALEXANDRIA, *The Pneumatics of Hero of Alexandria*, MARIE BOAS HALL, intro., MacDonald, London, 1971.
FRANCES HAWKINS, *The Logic of Action: from a teacher's notebook,* University of Colorado, Mountain View Center for Environmental Education, Boulder, CO, 1969.
IBN AL-HAYTHAM, *The Optics of Ibn al-Haytham. Books I-III, On direct vision*, A.I. SABRA, trans. and ed., Warburg Institute, University of London, 1989.
M.C. JOHNSON, "Greek, Moslem and Chinese Instrument Design in the Surviving Mongol Equatorials of 1279 AD", *Isis* 32 (1940), pp. 27-43.
ELAHEH KHEIRANDISH, "Footprints of 'Experiment' in Early Arabic Optics", in Evidence and Interpretation: Studies on Early Science and Medicine in honor of John E. Murdoch, *Early Science and Medicine* 14 (2009), pp. 79-104.
HARRIETT PRATT LATTIN, "Lupitus Barchinonensis", *Speculum* 7 (1932), 58-64.
HARRIETT PRATT LATTIN, *The Peasant Boy Who Became Pope: Story of Gerbert*, New York, 1951.
HARRIETT PRATT LATTIN, *The Letters of Gerbert*, Columbia U. Press, New York, 1961.
M.J.T. LEWIS, *Surveying Instruments of Greece and Rome*, Cambridge University Press, Cambridge UK, 2001.
HENRI MICHEL, "Les Tubes Optiques avant le Télescope", *Ciel et Terre* 70 (1954), pp. 175-183.
JOSEPH NEEDHAM, (1974), "Astronomy in Ancient and Medieval China", *Philosophical Transactions of the Royal Society of London*, Series A, 276, 67-82.
EMMANUEL POULLE, "L'Astronomie de Gerbert", *Gerberto, scienza, storia e mito: atti del Gerberti Symposium*, Bobbio 25-27 Luglio 1983, pp. 597-617.
RICHER OF SAINT-REMY, *Historia Francorum,* ROBERT LATOUCHE, (trans., ed.) *Histoire de France (888-995),* Vol. 2, H. Champion, Paris, 1930.
JOHN WARMAN, "The Hydraulic Organ of the Ancients", *Proceedings of the Musical Association* 30 (1903), pp. 37 -56.