Abstract

From October 2016 to April 2017, the Institute for the Study of the Ancient World (ISAW) at New York University was the venue for the exhibition Time and Cosmos in Greco-Roman Antiquity. Among the objects on display were ancient sundials, some of which were accompanied by digital animations that illustrated how such devices worked. The purpose of the current article is to place these digital resources in the context of the collaborative environment that created them and to show how they can continue to be effective in communicating the sometimes complicated operation of ancient sundials, including examples that were not on display in the gallery due to size constraints. After an introduction to the workings of the objects themselves, we discuss the role of this digital content in the visitor’s experience and as a museum education resource for docents.
Introduction

From October 19, 2016 to April 23, 2017, the Institute for the Study of the Ancient World (ISAW) at New York University was the venue for the exhibition *Time and Cosmos in Greco–Roman Antiquity* (Jones 2016). Twenty–seven lenders contributed more than one hundred objects ranging from sundials and calendars to ancient works of art that placed these time–tracking devices in their cultural context. Among the many goals of this international loan exhibition was to communicate to general audiences how Greek and Roman sundials functioned and were read in antiquity. We accomplished this in part by displaying digital animations that simulated the passage of light and shadow on the surfaces of three of the sundials that were on display. Figure 1 (above) shows the close association of physical object with its digital surrogate and indicates that visitors were able to take in both as they moved through the gallery. Additional animations allowed virtual incorporation of sundials that were not on display due to size or other practical constraints.

The purpose of the current article is to place these digital resources in the context of the collaborative environment that created them and to show how they are effective in communicating the sometimes complicated operation of ancient sundials. After an introduction to the workings of the objects themselves, we discuss the role of this digital content in the visitor’s experience and as a museum education resource for docents. The last section discusses the work to incorporate ancient sundials that could not be brought into the gallery because they are inscribed on a large building in Athens, Greece. Physical objects, the creation and use of their digital surrogates, and the interaction of visitors and guides with this material are the underlying focus throughout. Anecdotal feedback from visitors suggests that the animations were compelling and we hope that this aspect of the work is apparent in the current presentation. We also hope that placing these digital resources within a discussion of our goals is itself a pedagogic and professional resource for anyone considering similar work.
The exhibition *Time and Cosmos* drew on the expertise of many members of the ISAW community, and where possible we relied on open-source or free software and freely licensed content to create the digital resources that appeared in the galleries.[2] We believe these aspects of the work mean that our approach is repeatable in other institutional contexts. The authors of the current article are respectively a member of the faculty at ISAW, a member of the ISAW exhibitions staff, and an ISAW graduate student studying ancient science and its transmission in the Medieval and Early Modern periods. Our collaboration is founded on interactions that occurred within our academic context. In the spring of 2016, as the *Time and Cosmos* exhibition was in the planning stages, Heath taught the graduate seminar “Computational Photography and 3D Tools for the Ancient World.” An emphasis of the course was the use of open-source and free software and the potential for 3D animations to communicate visual aspects of scholarly work, including student initiated research (Heath 2015). Roughan, at the time in her first year of graduate work, enrolled in the course and chose as her project a virtual reconstruction of the Tower of the Winds, a Hellenistic-era octagonal monument in Athens well known for its sculpted personifications of winds that also had a sundial on each of its eight walls (Figure 14). Heath and Alexander Jones had already begun to collaborate on the animation of ancient sundials, inspired in part by the growing use of virtual tools to simulate ancient solar observations (Frischer et al. 2017), and it was clear that this work could have a role in the upcoming exhibition. Roughan’s student work on the Tower of the Winds also fit perfectly with the overarching theme of placing ancient technology in its cultural context. Heath’s seminar used the open-source animation suite Blender (2017) as its default digital tool. Accordingly, all the animations and renderings in this article were made, at least in part, with that software package. Herschman worked with both Roughan and Heath to develop the narrative aspects of the animations so that they would work effectively in the gallery and contribute to the educational mission of the exhibition (Wyman et al. 2011). We can say with confidence that digital pedagogy at the graduate level encouraged collaboration between many components of our small institution. We emphasize the collaborative nature of our effort for the very practical reason that it allowed all the work shown to be accomplished at low cost. In the past, such animations might have required a budget of tens of thousands of dollars at least. By taking advantage of open-source software, existing digital content where possible, previously purchased iPads, and our combined digital skills, the total incremental cost of including animations in the gallery was well under that amount.

**An Animated and Illustrated Introduction to Ancient Sundials**
Animations running on iPads were an important component of the *Time and Cosmos* exhibition. Accordingly, we include five animations in this section and six in the article overall. Figure 2 animates the passage of shadow across a Roman-period horizontal sundial from Pompeii in Italy as it would have appeared on the winter solstice, or December 21 or 22 in our modern calendar.[3] That is the shortest day of the year when the sun is low in the sky and shadows are long. Readers are encouraged to click on the image to initiate playback.[4] Achieving the combination of physical object and an animation showing how it worked was the main goal in creating these digital resources. It is of course the case that we cannot replicate that combination in this article. We can, however, place animations in the context of a narrative explanation of how sundials were used, which is what follows immediately here. The combination of viewing and reading is loosely analogous to the experience of listening to a gallery docent, a role explored further below. While an article is fundamentally different from what happens in a gallery, we hope readers are able to approach a more intimate understanding of these objects and then bring that perspective to our further discussion.

The principles that allowed an ancient sundial to be an effective time-keeping device can be expressed in straightforward terms.[5] As the sun is perceived to move during any given day from its rising in the east to its setting in the west, shadows cast by objects in the path of the sun’s rays will also move. A thin rod can cast a well-defined shadow and the movement of that shadow across a marked surface will indicate the passage of time. Additionally, the time of year also causes the length of cast shadows to change from day to day. At midday on the summer solstice, which often occurs on June 22 in our modern calendar, the sun will be at its highest point in the sky and shadows will be short on a sundial whose surface is oriented parallel to the ground. Six months later, at the winter solstice on or about December 22, the sun will be
relatively low at noon, meaning that shadows will be long. These, then, are the two major cycles that many ancient sundials utilized: a daily cycle for telling time, and an annual cycle used to indicate progression through the year.

Horizontal Sundial from Pompeii

*Figure 3: Rendering of shadow on the Pompeii Horizontal Sundial at three Roman hours before midday on the winter solstice, the shortest day of the year when the sun is low and shadows are long. The viewer is looking towards the south.*
Figure 4: Rendering of shadow on the Pompeii Horizontal Sundial at three Roman hours after midday on the winter solstice.

Just as animations in the gallery helped visitors understand the operation of the sundials they were viewing, the static illustrations and embedded animations in this article are intended to make the above description more accessible. Complementing the animation in Figure 2, Figure 3 renders shadow at three Roman hours before noon on the winter solstice as it would have appeared on the same horizontal sundial from Pompeii, the city in Italy most famous for having been destroyed by the volcano Vesuvius in 79 CE. A so-called horizontal sundial consists of a flat surface onto which a shadow is cast by a gnomon, which is the technical term for the pyramidal rod restored in Figures 2–6. This is the simplest form of ancient sundial and the most easily understood. Figure 4 shows the same sundial six Roman hours later, or three Roman hours after midday. In combination with Figure 2, Figures 5 and 6 show animations of shadow passing over the Pompeii sundial on the winter solstice (Figure 2 above), the spring equinox (Figure 5)—approximately March 22nd on our modern calendar when the day and night are of essentially equal length—and the summer solstice (Figure 6), when the sun is highest at noon and the shadow cast by the sundial’s gnomon is short. In combination with the still renderings, we intend that these digital surrogates for the physical object effectively communicate the way this sundial worked.
Figure 5: Animation of shadow on the Pompeii Horizontal Sundial at Spring equinox
Figure 6: Animation of shadow on the Pompeii Horizontal Sundial at Summer Solstice

A Double Sundial from Delos, Greece
Figure 7: Rendering of the Delos Double Spherical Sundial shortly after sunrise on spring equinox. In this rendering, the sun is low on the eastern horizon. As the sun rises in the sky, the shadow of the right-hand gnomon will move down the right-hand quarter sphere until midday, when the left-hand quarter-sphere will become readable.

The operation and reading of the Pompeii Horizontal sundial are relatively straightforward to represent in digital form, and the same basic principles are at work for all the sundials shown in this article. Figure 7 uses a simplified virtual space to show a so-called double-spherical sundial dated to the 3rd to 2nd century BCE and from the Aegean island of Delos.[6] Figure 7 shows the shadows cast by two virtually restored horizontal gnomons as they would have appeared early in the morning on the spring equinox. The sun is rising to the viewer’s right and the right-hand gnomon casts its shadow onto the right hand quarter sphere. Figure 8 shows the shadow approximately an hour before midday. Figure 9 is an animation of the shadow during the entire spring equinox, and readers may want to play that before reading further. The key movement the animations shows is that the readable shadow passes to the western curved surface after midday, meaning to the left of the rendered perspective. As noted, the basic principle is the same as seen on the Pompeii Horizontal Sundial. The Delos sundial is nonetheless a very clever arrangement of surfaces and gnomons and there is license to think that its designers enjoyed their work, though this is a purely speculative modern reaction.
Figure 8: Delos Double Spherical Sundial before midday on spring equinox. The right-gnomon is still casting the readable shadow, but this will change after midday as the sun moves to the left and casts the readable shadow on the left-hand quarter sphere.
“Roofed” Spherical Sundial

The next sundial we discuss here is a so-called roofed sundial said to be from Carthage in North Africa, but more likely intended to have been set up near Rome in Italy. This is a remarkable piece of ancient technology. Instead of having an upward-facing readable surface onto which a gnomon casts a shadow, a so-called roofed sundial is a downward-facing curved surface with a hole near its top. The light of the sun passes through the hole, or “oculus,” creating a bright spot in a field of shadow. The path that the spot travels serves the same purpose as the tip of the shadow of the gnomons in the previous two examples. Figure 10 renders the appearance of the working surface at one Roman hour before midday on the summer solstice.[7] The sun is very high so that much of the sundial is in shadow. The readable dot is just to the left of the lowest point. In this rendering, the viewer is looking north and the sun is both behind and slightly to the right, or east. Figure 11 is an animation of the path of the bright dot on the spring equinox.
Figure 10: Roofed Spherical Sundial showing the hour before midday on the summer solstice.
Figure 11: Animation of Roofed Spherical Sundial showing approximate movement of shadow and the bright spot indicating time during the spring equinox.

We have noted that the essential principle by which any sundial operates, the casting of shadow, is straightforward. The particulars can be complex and the gridlines on individual objects are difficult to understand without seeing shadows moving over them. We again encourage readers to play these animations and to see them as an essential—and we hope enjoyable—complement to our descriptions. By doing so, the role of these digital surrogates in the gallery experience is accessible. That experience is the topic of the next section.

Installation, Presentation, and Experience
The exhibitions program at ISAW is a powerful, public-facing visual expression of the research that takes place here. In addition to serving a scholarly community, the galleries are open to the public and admission is free of charge. *Time and Cosmos* was featured in high-circulation news publications, and attracted a broad audience (Wilford 2016; Rothstein 2017). Showcasing academic work to diverse audiences, ISAW exhibitions aim to make rigorous scholarship accessible and engaging to the varied communities that it serves.

For gallery visitors unfamiliar with Greco-Roman timekeeping instruments, the diversity of ancient sundial styles presented in the exhibition was often a surprise. To a general audience, the word “sundial” is often associated with an image of a flat disk and triangular, finlike gnomon, similar to what one might find in a garden. *Time and Cosmos* presented a range of differently shaped sundials that were understood in antiquity not only as tools to measure time’s passage but also as a representation of the cosmos, since the movement of the sun provided the organizing structure for the division of hours and seasons.

Contemporary clocks and watches do not reveal the science and math behind their functioning as ancient sundials do. Introducing this concept to visitors required not only an explanation of the many differently shaped sundials but also an efficient primer on Greco–Roman cosmology. Incorporating digital animations for a strategic selection of sundials was an important curatorial approach for showing how these instruments worked, as well as how they depicted the movement of the heavens in miniature. The video of the Double Spherical Sundial with Greek Inscriptions (Figure 9) illustrated how sundials reflected the two-sphere model of Greek cosmology—its shape is an inverted copy of the celestial sphere—and allowed visitors to understand quickly how all other sundials were different geometric representations of a spherical cosmos.

Representing movement was key to presenting these artifacts in an accessible way. Ancient sundials were not static or merely decorative objects, but performance instruments. Since all are missing their gnomons and were presented in a gallery with regulated artificial lighting, it was impossible to show visitors how the
sundials would have worked using the artifacts alone. Even a scale replica with a recreated gnomon
exhibited outdoors would not have been accurate: each sundial is calibrated to a particular latitude, one
different from New York City.

The animations were a way to overcome the static nature of the exhibition space, making it engaging for a
general visitor while at the same time presenting a specific and idealized representation of how these
artifacts would have been used by the ancients, down to the correct latitude. We were also able to optimize
the shadows by drawing them darker than they would have appeared under natural sunlight, for example.

The animations also allowed us to accelerate the sun’s movement over the course of a day, compressing
the sunrise-to–sunset cycle into a sequence approximately thirty seconds long. The same sequence was
repeated for the winter solstice, spring equinox, summer solstice, and autumn equinox—each time
showing the day getting longer or shorter according to the season. It was often a discovery for visitors that
ancient sundials not only showed the hour of the day but also indicated the season of the year (or in the
case of the Pompeii Horizontal Sundial, the zodiacal cycle of the sun). From a practical standpoint,
animating a day in fast–forward meant each video had a total runtime of approximately two minutes, which
ensured visitors kept moving through the gallery space without bottlenecks or overcrowding around
certain works.

ISAW offered free guided gallery tours to the public every Friday evening, and interested groups could also
prearrange private tours outside of the regular schedule. Led by qualified scholars and PhD candidates
with expertise in ancient science or art, docents engaged visitors with interactive, inquiry–based tours. The
animations provided useful tools to the docents and helped prompt questions about the artifacts on view.

As visitors observed the network of lines carved into a sundial’s face, the docents could direct their
attention to the animation below and point out how the shadow crossed them during the course of a day
and year.

In addition to a general visitor’s expectations of what constitutes a sundial in the first place, there was the
additional challenge that all of the sundials on display were missing their metal gnomons. The animations
helped to call visitors’ attention to this absence from the physical objects. Showing a sundial indoors is a
bit like showing a stopped clock, and to an untrained eye, looking at one without a gnomon can seem like
looking at a clock face with no hands. The animations not only helped overcome these exhibition
challenges by recreating the gnomon but also drew visitors’ attention back to the artifact itself. Pairing a
real sundial with an animation, gallery guests would compare the two and this often prompted questions
about the specific sundial: Why is the gnomon missing? What is the history of this specific artifact? On
guided tours, docents could discuss the widespread recycling of metals in antiquity and comment on how
the mathematical and calculable path of the sun (as viewed from earth) allows scholars today to
reconstruct exactly the gnomon necessary for the given sundial lines and latitude.

The animations were successful because they not only illustrated the larger principles of Greco–Roman
timekeeping and cosmology but also illuminated the specific artifacts on view, inviting a consideration of
their individual object histories. In a gallery setting, next to a real work of art, the animations pointed back
to the thing itself. Rather than serving as a substitute or competing with the object for a visitor’s attention,
the digital animations enhanced the experience of the stone sundials.

One example is our presentation of the Roofed Spherical Sundial with Greek Inscriptions. This sundial
marked a change from the other sundials included in the exhibition: it told time using a moving spot of
light within a shaded bowl (Figure 11). The underlying cosmology is consistent with the other videos, yet it
was important to demonstrate how to read this unique dial, and that the hole at the top was actually an
oculus and an important part of how the sundial functioned. The video clearly illustrated the
distinctiveness of this instrument’s operation, while echoing the same daily and seasonal patterns as the
other sundial videos.

Understanding the unique history of an individual sundial also helped reveal the larger cultural view of
time in antiquity and the greater context for such instruments. Again, the Roofed Spherical Sundial offers a
case in point. Although this piece is precisely calibrated for the latitude of Rome—it is described by the
exhibition’s curator Alexander Jones as a display of “mathematical virtuosity” (Jones 2016: 25)—its
findspot is recorded as Carthage, indicating that it was moved at some point in ancient history. At this
different latitude it would not have told time as precisely as it would have in Rome, but it does reveal that even in antiquity the sundial was valued as an art object as well as a timepiece. Elegantly carved to resemble a skyphos drinking cup with oak leaves and acorns (similar to first-century CE luxury silverwork) the artifact is a masterpiece of science and art.

The Roofed Spherical Sundial, presented on the same table and at the same height as the other sundials, often prompted questions from visitors about how it would have been installed in antiquity. To view the interior of the sundial, visitors would have to lower their heads and look up into it (Figure 1). The docent could direct gallery guests to the animation, which displays the correct viewing angle (from below the sundial) before drawing their attention to the depiction of a sundial atop a column in the Roman Mosaic Depicting the Seven Sages (“Plato’s Academy”) on the gallery wall across from the sundial (Figure 13). The mosaic shows a sundial mounted above the heads of the assembled philosophers in a symposium-style setting. Bridging the presentation of a scientific instrument with an interpretation for other artworks, the animations helped unite different curatorial themes, including a sundial’s association with wisdom, by emphasizing its actual position.
There were several visualizations in the exhibition that brought in relevant material that could not be physically present in the galleries. An animation was the vehicle that presented a masterpiece of ancient architectural and scientific design: the Tower of the Winds. This construction, also known by the name the Horologion of Andronikos, is a 13.5-meter tall marble octagonal tower located beside the Roman Agora of Athens. Its eight walls each face a cardinal or intercardinal direction and are topped by friezes depicting the personified wind deity of that direction. Its relevance to the exhibition however is as a horologium: the tower itself is a monumental and multifaceted sundial. Carved into each of the eight walls is a vertical sundial calibrated for the direction in question.

While the tower could not be situated in the gallery space for obvious reasons, an iPad with the animation was paired with one of the other gallery objects. The Double Vertical Sundial from Delos provided another model of a vertical sundial, this one with its faces directed southeast and southwest (Figure 15). The museum visitor could observe that the layout of the sundials on these faces matched those on two walls of the Tower of the Winds.
The Tower of the Winds animation required the most original work and has its origins in a graduate seminar on 3D technologies taught at ISAW. As noted in the introduction to this article, that seminar was taught by Heath in Spring of 2016 and attracted PhD students from ISAW, NYU’s Institute of Fine Arts, and the Anthropology Department. Its focus was on using 3D tools to communicate aspects of students’ own research so that rendering the movement of shadow on the Tower of the Winds was a very suitable project to take on during the term. The final realization of the animation, and the following discussion, is the work of C. Roughan. 3D model data for the Tower of the Winds did not exist so the model was built using the comprehensive measurements presented by Stuart and Revett (1762) and the updated and more precise numbers in Kienast (2014). This data encompassed architectural components on a large scale and down to details such as the moldings. More significantly, a chapter by Karlheinz Schaldach in Kienast (2014) measured the angles of the octagonal walls and the layout of the sundials to a high degree of precision.
The 3D modeling software SketchUp was used to build the model of the tower from this data, while textures for the model were produced from photographs of the tower in the open source image editor GIMP.

Like the other sundials, the animation for the Tower of the Winds was created using Blender. The Tower of the Winds did present two challenges to its animation: it was desirable to depict the tower as a work of architecture in its surrounding city and it was necessary to present to the viewer the operation of eight different sundials on one piece. The former goal was accomplished by placing the Tower of the Winds model into a CC-BY-NC model of second century CE Athens which was available in Blend Swap, a repository for open source Blender models (Aguirre 2014). The latter was accomplished with a moving camera, which circled around the tower and followed the sunlight as it illuminated and cast shadows on the eight walls and sundials of the structure.

\[\text{Figure 16: Animation of the Tower of the Winds at the Spring Equinox}\]

The moving camera guides the viewer’s understanding of the Tower of the Winds. The full animation opens with a shot of the full tower before circling and panning to present it in the context of the surrounding city of Athens. With this accomplished, the camera then zooms in to circle the tower itself and display the workings of all eight sundials (Figure 16). These choices aimed to acquaint the viewer with the tower in its entirety and in its public setting—details that were key because the tower could not be physically present.

In the exhibition the Tower of the Winds animation joined harmoniously with the other pieces to tell the story of the many and varied sundials in antiquity. The positioning of the iPad with the Tower of the Winds meant that most tours approached it after previous works had prompted discussion about typical settings for sundials, the varying sundial faces, the sundial as an artistic object, and the sundial as a display of ancient cultures’ mastery over the cosmos. All of these themes prove very relevant to any discussion of the
Tower of the Winds. As the tour came to the animation of the tower, members of the public—already introduced to sundials situated in public contexts, to sundial faces calculated for different projections and directions, and to sundials which boasted of both artistic and scientific skill—could appreciate these elements in a single and monumental work.

Conclusion

We close by re-emphasizing the collaborative nature of our work. It is not new to place animations in a gallery setting. In 2017, however, it was possible to use relatively low-cost tools and openly licensed data to achieve the digital manifestation of ISAW’s in–house expertise that appear above. Faculty, exhibition staff, and graduate students worked together closely on this project. While the proximate intended beneficiaries of this effort were the members of the public who visited the galleries while the Time and Cosmos exhibition was installed, presenting the animations in this publication allows its results to reach a wider audience.

Notes

[1] The exhibition was curated by Alexander Jones, Professor of the History of the Exact Sciences in Antiquity (ISAW); the acknowledgements on pp. 12–15 of Jones 2016 directly credit all those who had a role in its success. The authors of this article are grateful to the JITP editors and to the anonymous readers for their comments.

[2] ISAW is constituted as a separate academic unit within New York University, but is analogous in scale to an individual department. There are eleven full–time faculty, approximately twenty graduate students, and twenty staff. Additional information about ISAW is available online at http://isaw.nyu.edu/ (http://isaw.nyu.edu/)

[3] Brief catalog information of all the objects discussed here follows the main text. The underlying model for the animation in Figure 2 was prepared in Blender using photography by Guido Petruccioli. The shadows were animated using the “Sun Position” Blender add–on.

[4] The exact interface for initiating playback will depend on which browser a reader is using. As of this writing, most browsers display a small set of controls below the video that have the familiar “play” right pointing triangle icon


[6] The model used to create this image and related animation is available via the Berlin Sun Dial Project (2012). BSDP data is available under a Creative Commons Attribution Non–Commercial Share–Alike license, which very much simplified our ability to integrate the Delos Double Spherical Sundial model into the gallery experience and into this article.

[7] This model was prepared by Alexander Jones by compiling multiple photographs into 3D data using a technique known as photogrammetry that is becoming very common in art–historical and archaeological studies (Olson et al. 2013).

Catalogue

1. Horizontal Sundial with Greek Inscriptions. Marble, H. 53 cm; W. 34.5 cm; D. 3 cm, Pompeii, before 79 CE. Museo Archeologico Nazionale di Napoli: 2476. (Figures 2–6). Jones 2016, no. 7.

2. Double Spherical Sundial with Greek Inscriptions. White marble, H. 45 cm; W. 32 cm; D. 19 cm, Gymnasium, Delos, 2nd century BCE. Archaeological Museum, Delos: B4367. (Figures 7–9). Jones 2016, no. 2.


4. Double Vertical Sundial. White marble, H. 29.6 cm; W. 21 cm; D. 14 cm, Oikos of Dionysos, Delos, ca. 100 BCE. Archaeological Museum, Delos: B594. (Figure 15). Jones 2016, no. 8.

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