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Matthews, Michael R.

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The International Pendulum Project

Michael R. Matthews

m.matthews@unsw.edu.au

School of Education, University of New South Wales, Sydney 2052, Australia

The Pendulum in Modern Science

Galileo in his final great work, *The Two New Sciences*, written during the period of house arrest after the trial that, for many, marked the beginning of the Modern Age, wrote:

We come now to the other questions, relating to pendulums, a subject which may appear to many exceedingly arid, especially to those philosophers who are continually occupied with the more profound questions of nature. Nevertheless, the problem is one which I do not scorn. I am encouraged by the example of Aristotle whom I admire especially because he did not fail to discuss every subject which he thought in any degree worthy of consideration. (Galileo 1638/1954, pp.94-95)

This was the pendulum's low-key introduction to the stage of modern science and modern society. At the time pendulum studies certainly would have seemed 'exceedingly arid' compared to the more profound questions of nature such as what intelligences drive the planets? What events are heralded by the appearance of comets? What maintains projectiles in flight after they have left the hand? And so on. Notwithstanding its humble introduction, the pendulum went on to a starring role in classical science and, especially through time-keeping, in modern culture and society.

The pendulum was extensively studied by Galileo (Naylor 1974, Drake 1990, Matthews 2000, chap.4, Newton 2004). It was important for establishing Galileo's new science: the bulk of Day Three of his 1638 *Discourse* is taken up with discussion of its properties. In 1639, three years before his death, in a letter to a friend Baliani, he says that his successful investigation of free fall – a long standing problem for natural philosophers since Aristotle – was due to 'the marvellous property of the pendulum, which is that it makes all its vibrations, large or small, in equal times' (Drake 1978, p.399).

Christiaan Huygens work in mechanics was centered on the analysis of pendular phenomena, and he provided the first detailed theoretical and practical guide for the utilisation of pendulum motion clockwork thus transforming the accuracy of time measurement (Huygens 1673/1986, Matthews 2000 chap.6). Robert Hooke and all the leading figures of seventeenth-century science engaged in and utilised pendulum studies (Patterson 1952).

The pendulum was nowhere more important and central than in the foundation that Newton laid for modern science (Matthews 2000 chap.8). The

historian Richard Westfall correctly remarked that ‘without the pendulum, there would be no *Principia*’ (Westfall 1990, p.82). For Newton and his contemporaries the pendulum was crucial for establishing the collision laws, the conservation laws, the value of the acceleration due to gravity g , and ascertaining the variation in g from equatorial to polar regions and hence discovering the oblate shape of the earth (Heiskanen & Vening Meinesz 1958).

Most importantly for Newton, the pendulum provided the crucial evidence for his synthesis of terrestrial and celestial mechanics (Boulos 2005). When Newton calculated the ‘fall’ of the moon in one second, and showed that it was precisely the portion of the fall of the pendulum predicted by his law of universal gravitation, he was able to demonstrate his claim that the heavens (moon and planets) obeyed the same laws as earthly bodies such as falling stones and projectiles. The heavens ceased to be a special realm of the Gods, or of essentially different substance from terrestrial material. The pendulum brought the heavens down to earth, so to speak.

Subsequently the pendulum was at the core of classical mechanics as it developed through the eighteenth, nineteenth and early twentieth centuries, with the work of Stokes (1851), Atwood and Eötvös being especially notable. The pendulum provided the first ever visible and dynamic ‘proof’ of the rotation of the earth. On February 2nd, 1851 Léon Foucault invited the French scientific community to ‘to come see the Earth turn, tomorrow, from three to five, at Meridian Hall of the Paris Observatory’ (Tobin 2003, Aczel 2003, 2005). His eponymously named long massive pendulum provided an experimental ‘proof’ of the Copernican theory; something that eluded Galileo, Newton and all the other mathematical and scientific luminaries who sought it.

Until Foucault’s demonstration all astronomical observations could be fitted, with suitable adjustments such as those made by Tycho Brahe, to the stationary earth theory of the Christian tradition. The ‘legitimacy’ of such *ad hoc* adjustments in order to preserve the geocentric model of the solar system was exploited by the Catholic Church that kept the works of Copernicus and Galileo on the *Index of Prohibited Books* up until 1835 (Fantoli 1994, p.473). Mach of course disputed whether the rotation of Foucault’s pendulum provided a proof, arguing that the rotation assumed a standpoint frame of reference, an argument repeated by some relativity theorists who maintained that absolute motion simply cannot be detected. But certainly to the lay person and to most 19th century physicists, the manifest rotation of Foucault’s pendulum shown in the successive knocking down of markers placed in a circle, was a dramatic proof of the earth’s rotation.

Among all the other contributions of the pendulum to the growth of modern science one is particularly worthy of mention: the pendulum’s role in establishing the first universal standard of length, the metre. In modern textbooks the metre is introduced in the opening pages on Physical Standards as ‘the length of path travelled by light in vacuum during a time interval of $1/299,792,458$ of a second’. This was the decision of the 1983 General Conference on Weights and Measures. For students it is of course a completely bizarre notion, and perhaps confirms their already existing ideas that science is bizarre. An older text might state that the metre is one 40th million part of the circumference of the earth. This is less bizarre, it is at least

imaginable, but it still appears as a completely arbitrary decision. Why choose such a fraction of the earth's circumference? The answer, of course, is that it coincides almost exactly with the length of the seconds pendulum which is 0.997m in Paris. The connection of the seconds pendulum, first proposed by Huygens as an international length standard in 1673, to the modern metre standard is a most interesting, but usually untold, historical story with scientific, methodological and political dimensions (Matthews 2000, pp.141-150, Alder 2002).

The Pendulum's Shadow in Science Education

Despite the pendulum's starring role in science and culture the pendulum is mostly overlooked by science teachers. It is still an 'arid' topic, it is frequently voted 'most boring' topic in the syllabus, and is often simply left out of school programmes altogether. This neglect of the pendulum is a great pity as it diminishes students' opportunity to develop a sound knowledge of science, its processes, and its interactions with mathematics, technology, culture and society. Also missed is a fruitful opportunity to learn about the Nature of Science; and, importantly, an opportunity for students to develop a sense of belonging to a scientific cultural tradition, with its own heroes, achievements norms, values, outlooks and 'habits of mind', is foregone. This is a particularly unfortunate consequence at the present time where so many conflicts in the world would benefit from participants being more scientific in their approach to divisive issues and ideologies.

The pendulum is simple, tangible, cheap, and easy to manipulate; it can profitably be used from primary schools through high schools to university; it can be configured in a variety of ways in order to investigate elastic and inelastic collisions, and hence to demonstrate conservation laws of momentum and kinetic energy; it is an admirable vehicle for the conduct of 'historical-investigative' teaching, whereby students retrace the intellectual arguments and recreate the experimental demonstrations of earlier eras in science (Kipnis 1996); and it can be the occasion for rich and engaging cross-disciplinary teaching among science, mathematics, history, technology, literature, geography and religion faculties.

The Pendulum Project

The *International Pendulum Project* (IPP) had its origins with the publication of the book *Time for Science Education: How Teaching the History and Philosophy of Pendulum Motion can Contribute to Science Literacy* (Matthews 2000). This was a 13-chapter book with 1,200 references. It ranged widely over the history, methodology, cultural impact and pedagogy of pendulum studies. Interest in the subject matter of the book was sufficient to bring a large international group of scholars together for conferences at the University of New South Wales in 2002 and again in 2005. Participants saw the need to make teachers and students more aware of the important role played by the

pendulum in the history of science and to investigate and promote better and more enriched pendulum teaching in schools. Participants in the IPP believe that the pendulum provides an accessible point of entry, or door, for students to learn important components of scientific knowledge, key features of scientific method, and important aspects of the interplay between science and its social and cultural context.

Scholars from twenty countries have contributed to the IPP, and their research has appeared in three special issues of the journal *Science & Education* (vol.13 nos.4-5, 7-8, vol.15 no.6). Thirty-three papers have been published in the anthology *The Pendulum: Scientific, Historical, Philosophical and Educational Perspectives* (M.R. Matthews, C.F. Gauld & A. Stinner eds., Springer, 2005). The IPP has a web site where further details and publications can be found: www.arts.unsw.edu.au/pendulum/.

The publications of the IPP establish that a good pendulum-based course or unit allows students to learn:

- (i) Basic scientific knowledge, such as the laws of fall, laws of motion, collision laws, and the laws of conservation of momentum and energy.
- (ii) Essential features of scientific inquiry, such as observation, measurement, data collection, control of variables, experimentation, idealisation, and the use of various mathematical representations.
- (iii) Important aspects of how science interrelates with society, culture and technology, as manifest in the use of the pendulum in timekeeping, navigation, length standards, and so on.

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