Institution:	**Cardiff University**
Unit of Assessment:	**9**
Title of case study:	**The Antikythera Mechanism: seeing inside a two-thousand-year-old computer**

1. Summary of the impact

Research led by the Cardiff University School of Physics and Astronomy has identified the world's earliest known astronomical calculator. The Antikythera Mechanism was discovered in 1900, in a Mediterranean shipwreck from the first century BC. However, its function and workings remained unclear until Cardiff University Astronomy Professor Mike Edmunds initiated and led an international research project. The results, showing that the mechanism was an astronomical calculator of extraordinary technical and mathematical sophistication, have revolutionised worldwide public understanding of key aspects of ancient Greek civilisation. Moreover, X-ray imaging technology specifically developed to analyse the mechanism, has generated approximately £15M turnover. The impacts are therefore extensive public engagement and significant economic gain.

2. Underpinning research

In 1999 Edmunds directed an undergraduate student project to review what was then known about the Antikythera Mechanism and suggest how it might have displayed the positions of the planets in the sky. That work [3.1], highlighted the need to find out more about the internal structure of the artefact. This was problematic due to its fragility and archaeological status. However, Edmunds established and led a team with the objective of adapting and using modern non-destructive 3-D imaging technology to probe the interior of the device. The project was awarded a research grant by the Leverhulme Trust [3.2] in 2004 with Edmunds (Cardiff 1974–2007; now Emeritus) as P.I. and Freeth (Cardiff. Jan 2005 – Dec. 2006; employed by Cardiff as a contractor under the grant). Edmunds led the programme, involving academics in the UK, Greece and the USA. Hewlett-Packard and a corporation then called X-Tec developed customised 3-D surface and state-of-the-art internal X-ray microfocus computed tomography systems especially for the work.

Prof Mike Edmunds inspects the Antikythera Mechanism in the National Archaeological Museum in Athens

Extensive imaging of the surface and interior of the artefact was undertaken in Greece in 2005, following permission from the Greek Government. The initial results of the research were announced at a conference in Athens in November 2006, with simultaneous publication (including favourable editorial comment) in *Nature* [3.3; Edmunds was stated as the academic lead and responsible for the statistical analysis]. The results revealed that the mechanism is indeed a genuine artefact from around 140-100 BC, and originally contained over 30 gear wheels. Based on the team's analysis of the teeth counts of the gears and the mechanical structure, and their deciphering of text inscriptions on the device, they established that it displayed the position of the Sun and Moon in the Zodiac, the phases of the Moon and the Metonic lunar-solar calendar. It had a dial to predict the occurrence of lunar and solar eclipses using the Saros eclipse cycle, and a dial to indicate the four-yearly cycle of the pan-Hellenic games, including the Olympics. Perhaps the most extraordinary surviving feature is its ability to show the first anomaly of the lunar motion at its correct period, which involves two interlaced gear trains, epicyclic gearing and a variable-speed device, showing great sophistication of mechanical design. The mechanism almost certainly originally showed planetary positions, and although most of this part is lost, the surviving evidence is leading to interesting speculation about its possible structure. Subsequent research papers led by Edmunds appeared in 2011 [3.4, 3.5].

The Antikythera mechanism is both the earliest known geared mechanism (with the earliest known scales or dials) and the earliest known mechanical calculator. Nothing as complicated is known until the era of the medieval cathedral clocks, some 1400 years later.

3. References to the research (citation numbers from Google Scholar, 29 Oct. 2013)

3.1 **Edmunds**, M. G., and **Morgan**, P., Antikythera: Still a Mystery of Greek Astronomy?, *Astronomy & Geophysics,* 6.10-6.17, 2000 [10.1046/j.1468-4004.2000.41610.x]; 23 citations

3.2 Leverhulme grant: P.I. Prof M. G. **Edmunds**, *New Investigations of the Antikythera Mechanism*, Ref F/00 407/AA, 15/11/2004, £164,353 for 2 years.

3.3 **Freeth**, T., Bitsakis, Y., Moussas, X., Seiradakis, J. H., Tselikas, A., Mangou, H., Zafeiropoulou, M., Hadland, R., Bate, D., Ramsey, A., Allen, M., Crawley, A., Hockley, P., Malzbender, T., Gelb, D., Ambrisco W., and **Edmunds**, M. G., Decoding the Ancient Greek Astronomical Calculator Known as the Antikythera Mechanism, *Nature*, 444, 587, 2006 [10.1038/nature05357]; 119 citations

3.4 **Edmunds**, M. G., and Freeth, T., Using Computation to Decode the First Known Computer, *Computer*, 44, 7, 2011, 32 [10.1109/MC.2011.134]; 1 citation

3.5 **Edmunds**, M. G., An Initial Assessment of the Accuracy of the Gear Trains in the Antikythera Mechanism, *J. History of Astronomy*, 42, 307, 2011; 6 citations; no DOI: Copy available from the HEI.

4. Details of the impact

Public engagement – social, educational, and cultural: The extent of the ancient Greeks' mechanical design ability and their degree of astronomical knowledge has been reassessed as a direct consequence of this Cardiff University led research. The previously unrecognised and fascinating findings (following the publication in *Nature*) have inspired worldwide interest, initiating an abundance of UK and international media articles, broadcasts, web reviews, documentaries, a book, website and commemorative watch. This coverage, as evidenced below, was entirely dependent on the research which has definitively reconfigured global public understanding of the capabilities and sophistication of an important ancient civilisation. This is profoundly relevant both to cultural history and to the history of technology.

From January 2008 to February 2013 Prof Edmunds and the Antikythera Project have featured in 98 separate items of media coverage, with newspaper, magazine and web items across the world. Examples include *The New Zealand Herald*, *The Courier Mail* (Australia), *The International Herald Tribune*, *The Vancouver Sun*, *The Daily Mail*, *The Sunday Telegraph*, *Cyprus Mail*, *Hindustan Times*, *The Houston Chronicle* (American's 6th largest newspaper) and *The New York Times*. Websites such as *National Geographic*, *Scientific American*, *Houston Museum* and *Huffington Post* have featured the research (some examples are given in refs. 5.1 to 5.3). Additionally, the Antikiythera project's website (www.antikythera-mechanism.gr) has maintained a high position in search engines since 2006 (usually second after Wikipedia) and attracted 561,059 visits (from Jan. 2008 – Dec. 2012), with a high concentration of visitors in the USA, Greece, UK, Canada, Germany, France, Australia, Netherlands, Italy and Spain, and new visits accounting for 82%. Reconstructions have also appeared on the web, including a Lego model of the functionality of the device (based on and referring to the Cardiff-led research). This was constructed in 2010 and the YouTube video (http://www.youtube.com/watch?v=RLPVCJjTNgk) has had over two million views.

Several TV documentaries have featured the research. Edmunds participated in filming for an international TV production involving ERT (Greek Radio Television S.A.), ARTE (Association Relative à la Télévision Européenne) and NHK (Japan Broadcasting Corporation) in the summer of 2011. The resulting programme *The World's First Computer, Decoding the Antikythera Mechanism* was premiered in Europe (Greece, France, Germany etc.) in April 2012. It was also broadcast on BBC 4 as *The 2000 Year Old Computer*, with 13 showings between May and Feb. 2013, ranking twice in the top three of BBC 4's most popular programmes of the week, and attracting audience figures of more than 2.5 million in 2012 [5.4]. It also won the top prize at the 2012 International Festival of Archaeological Film in Rovereto, Italy, and the Audience Award at the 12th International Film Festival of the Bidassoa in Spain [5.5]. The programme was also broadcast by NOVA (PBS) in the USA in November 2012 and again in April 2013.

A book, *Decoding the Heavens* (http://www.decodingtheheavens.com/) was stimulated by the research, and published in the UK, US, Greece, Germany, Japan, Taiwan and Poland in 2009 and short-listed for the 2009 Royal Society Science Book Prize. The author, Jo Marchant, states that "research by Mike Edmunds and his colleagues is what first got me interested in the Antikythera mechanism" and that her primary investigations for the publication centred on obtaining information directly from Edmunds [5.6].

A commemorative watch based on the mechanism was designed by Hublot in 2011 (http://www.rgholland.com/blog/hublot-antikythera/). This was the first watch to be inspired by archaeological evidence. Only four were manufactured with the intention to exhibit three in the Athens Museum, the Museé des Arts de Métiers, and the Hublot Museum. The fourth watch will be auctioned for charity in 2014.

The research has also been disseminated to the public at more than 50 talks given by members of the research team. Edmunds himself gave over 37 talks from 2009-2012. Audiences included members of industry (13%), school children (34%) and the general public (53%), at locations across the UK, Ireland, USA, Holland, Germany, Sweden and South Africa. The total number of attendees exceeded 2,500. All of the event organisers interviewed agreed that the research had provided the audience with new information which had changed their view of ancient Greek technology. For example, Russell Haines, Chair (2007-2012) of the Bristol branch of the Institution of Engineering and Technology (IET), organised a talk in the UK and afterwards commented that he thought "the ancient civilisations were far more intelligent and accomplished than even most people give them credit for", and that "very complex calculations and astronomical predictions can be made with mechanical devices" [5.7].

The Greek government has benefited from an increase in visitor numbers to the National Archaeological Museum in Athens where the mechanism is exhibited (http://www.namuseum.gr/exhibitions/temporary/n_temporary-en.html). The museum typically attracts 300,000-400,000 visitors per year. However, records (on file) show that in the period January-June 2012 visitor numbers have increased by 86% relative to the same period in 2011. A special year-long exhibition of the artefacts from the shipwreck, featuring the research opened in April 2012, contributing to this increase. This contrasts to other museums in Greece which have suffered a general fall in numbers.

Prior to the research, the mechanism was little known amongst the public. Today, a Google search on "Antikythera Mechanism" results in 338,000 hits.

Economic gain: The research has generated sizeable economic gains, enabling technology companies, the Greek government, media organisations and the publishing industry to benefit. The CT scanner used in the research was upgraded specifically for the project by X-Tec, by doubling the operating voltage from 225 kV to 450 kV to enable penetration of the entire mechanism. Based on the great success of the mechanism imaging, they realised that the increased penetration meant that they could use the equipment for other purposes. The 225 kV devices had been used to look at solder joints in ball grid array surface mounting packages in circuit boards. The upgraded device had sufficient penetration to look through aircraft engine turbine blades, providing a cheaper and more effective method of establishing internal integrity – formerly an expensive and destructive process. This development, according to Roger Hadland, Director of X-Tec, allowed the company to be sold to Nexus for ten times the value of previous offers, and it was subsequently acquired by Nikon. To date they have sold nineteen devices (called Bladerunner) and six are in production (three have been bought by Rolls Royce). The base price is £600k with the average sale price £750-800k. Roger Hadland [5.8] commented that "The Antikythera work was the spur to develop a new range of high powered microfocus X-ray sources. But as soon as the equipment was returned to the UK, we started trial scanning of turbine blades. The detail and precision of the 2D and 3D CT information was stunning, far better than any competition . . . X-Tek is now part of Nikon, with the Bladerunner accounting for a large proportion of X-ray production". The technology has thus not only secured financial benefits for X-Tec/Nikon but has significantly improved vital inspection processes available to aircraft engineering industries.

Other parties financially benefiting from the research include the author and publishers of the book about the Antikythera mechanism and the media industry. *Decoding the Heavens* has sold over 5,700 copies to date.

In summary, the Cardiff-led research on the Antikythera mechanism has transformed our understanding of the capabilities of the ancients, led to the development of powerful non-destructive imaging technology for industry, and generated great public interest and media activity.

5. Sources to corroborate the impact

5.1 *New York Times* article, July 31 2008 is an example of positive media coverage: http://www.nytimes.com/2008/07/31/science/31computer.html

5.2 *Huffington Post* article, 2 May 2012 is an example of positive media coverage: http://www.huffingtonpost.com/2012/05/11/antikythera-mechanism-worlds-oldest-computer_n_1509575.html

5.3 *The Guardian* on-line article by Michael White, 6 June 2012 is an example of positive media coverage: http://www.guardian.co.uk/science/2012/jun/06/extraordinary-2000-year-old-computer

5.4 Data available from the Broadcasters Audience Research Board (BARB) website at http://www.barb.co.uk/viewing/weekly-top-10? corroborates the audience information given in about the TV documentary shown on BBC-4.

5.5 Statements about the prizes awarded to the documentary film *The World's First Computer, Decoding the Antikythera Mechanism* are confirmed at the Electric Sky Programme Sales and Licencing website: http://www.electricsky.com/catalogue_detail.aspx?program=3262.

5.6 E-mail statement by the author of *Decoding the Heavens* concerning her interaction with Prof. Edmunds, and confirming the quote attributed to her.

5.7 Transcript of interview with the Chair, IET Bristol (2007 – 2012), confirming the statement attributed to him in Section 4 and commenting on the quality of the talk delivered by Prof. Edmunds.

5.8 The former Director and Chief Engineer of X-Tek (now with Nikon Metrology), can confirm the statement attributed to him and the commercial impact associated with the imaging technology.

5.9 Prof. Edmunds was commissioned to write the Antikythera Mechanism entry in *Encyclopaedia Britannica*: http://www.britannica.com/EBchecked/topic/1334586/Antikythera-mechanism.

5.10 The Wikipedia entry, http://en.wikipedia.org/wiki/Antikythera_mechanism, gives a reasonable summary both of previous research and the impact of the current project.

Copies of all webpages, documents and testimony are available from the HEI on request.