The Language of the Universe

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Summary

This thesis consists of a sequence of five scripts for a television series that seeks to articulate the history of mathematics through key events and figures. Programme One examines the idea of zero, while Programme Two looks at how much of geometry was developed by mathematicians who examined the stars and led on to Einstein's work on relativity. Programme Three explores the history of codes and Programme Four complements this by examining how understanding triangles in different contexts was used to solve contemporary problems. Finally, Programme Five looks at an area of mathematics that many people find counter-intuitive, the measurement of chance events.

Behind the series lies the desire both to entertain and educate the audience, but also to demonstrate how the art of the documentary can be applied to science topics in a dramatic and imaginative way. The question of the documentary and its nature is discussed in the initial critical chapters that chart the development of the programmes and discuss the creative and technical issues they raise, together with a reflection on the learning process involved in their writing.

I should like to acknowledge the support of my first supervisor, Mr Norman Schwenk, and my second supervisor, Professor Martin Coyle. It is thanks to Mr Schwenk that the creativity was developed in this project, and it is thanks to Professor Coyle's advice and guidance that it is academically rigorous.

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CHAPTER ONE

Mathematics and the Television Documentary: Some Issues and Problems

Introduction

The essence of this project is the creation of a television documentary script on the history and story of mathematics. I started the project with the University because I saw it as an opportunity to develop my skills in writing professional documentaries. As I am already a published author of books, it seemed a natural progression to find a new market for my writing. I now realise with hindsight that this was somewhat naïve, but then that is one of the benefits of the learning experience of research. In this critical commentary I will argue that it is possible through the medium of television to show, and interest an audience in, the socio-history of mathematics in a form that they can understand (cf. Kilborn and Izod 1997:4).

It is, however, important to point out from the start that this project was limited in its scope to just the writing of documentary and not to its actual production. What is quite clear from the research that I have undertaken is that in many cases there is never a final version of the script until the filming is done and even then changes to the actuality that is recorded can be made as part of the editing process. Thus, while it is the case that the script during the production of a documentary continues to develop, it nevertheless remains a complete whole as a script and in that sense a piece of creative writing. It also needs to be stated that the form in which this work is being presented is not the usual style of documentary script. The conventional style would be to present a written description of the image (Hampe 1997: 133). However, it was felt advisable to illustrate this work with suitable examples of the type of image that would be used in real programmes. It needs to be understood that the images are exemplars only and would change in the production of the work.

The Nature of the Project

The Language of the Universe is a script for a television series that gives a glimpse into the fascinating history and development of the science of mathematics. The project is a study of the people who formed the subject, rather than of the abstract thinking inherent in the subject. And this is for a good reason: mathematics is a subject where people have created new ways of thinking, new concepts that analyse and explain the real world that surrounds us, and this is its strength.

The story of mathematics is fascinating; it is a human story, a story of drama, power and intrigue and that is why I wanted to write it. I also believe that a series on the abstract nature of mathematics simply would not be commissioned and this is an inherent weakness of representing the subject through the medium of television. As a writer, the reason for writing this project is not a desire to amuse the viewer but stems from, as Anne Brontë put it, more a need to tell the truth as I see it, 'for truth always contains its own moral for those able to see it' (Taylor 2000: 40). It is also important to note that whilst this project has been in development, both Terry Jones and Jeremy Clarkson have produced films that are very similar to the programme on numbers and the programme on codes. It would thus appear that there is a renewed interest in exploring mathematics through the documentary form, in order to give the subject a living concreteness and a visible presence.

Approaching the Documentary

I have previous experience of broadcasting and I am a qualified teacher of mathematics. As well as this I have also published non-fiction mathematics books. I therefore saw this project as an opportunity to draw these aspects of my professional skills together.

But why write for television? As a child, television was my entrance to a world of information. It was my way of constructing part of my social identity and it was television that gave me access to other experiences that, as a boy growing up, would have been otherwise denied (Murdock in Gripsrud 1999:11). It is this provision of different experiences to the viewer that makes television an attractive medium to the writer. However, the fact is that in Britain we have an antipathy, that is not new, towards mathematics as a subject (see Snow 1998). There are, therefore, considerable challenges in writing about mathematics for a popular audience, but also opportunities and risks that can stimulate the creative writer.

Teaching means one has to develop a certain level of presentational skill to keep the interest of children, but also one has to be creative. The same need for creativity holds good for documentary, in terms of the blend of narration and visuals. There needs to be a sense that the audience's desire to know something has been fulfilled (Nichols 2001:40). It is also the case that viewers who favour documentary programmes have a fundamental desire to know more about the real world and this correlates with their experiencing a stronger interest in the world represented on the screen than in the manner in which it is shown (Kilborn and Izod 1997:12). More generally, it is accepted that documentaries educate their audiences and share one or more of the following goals (Ohayon 2006). They aim:

- to document a subject to preserve knowledge;
- to reveal something new;
- to provide the viewer at home with access to a new experience, albeit second hand;
- to promote the importance of the subject.

In effect, every aspect of style in a documentary programme is designed to persuade the viewer that the film-makers were present there, that is, at the actual moment, and that in viewing the 'historical world through transparent and referential indexical images, we have shared that experience' (Kilborn and Izod 1997:37).

There is, therefore, a sense that as viewers we bring a culture of expectation to a documentary and we expect the documentary to illuminate our understanding. This means that as a writer it is up to me to exploit this expectation and to have a good, dramatic story (that fascinates the viewer) to tell (Rosenthal 2002:11). Most programmes must also play to as large a section as possible of the viewing public. In this sense they are consciously accommodated, or shaped to fit, the perceived values and interests of the target audience (Kilborn and Izod 1997:39).

This in turn is part of the justification for providing the audience with stories of the people involved in the history of mathematics as a science rather than in terms of the abstractions that are so commonly perceived as being the reality of the subject. At the same time, using images of science can be beneficial in understanding the nature of the documentary. Bill Nichols uses a circular definition that documentaries are what people who produce them make (Nichols 2001:22). This is not the most helpful of additions to the argument. Richard Kilborn and John Izod assert that the word documentary has become a portmanteau word with multiple points of reference (Kilborn and Izod 1997:13) This seems to be a more useful definition that takes into account the diverse nature of the documentary. When we compare this statement with Grierson's definition of documentary as the 'creative treatment of actuality', we can see that in defining the term we also come to it with our own set of values and expectations (Winston 1995:11). Again, from the experience of watching television documentary we understand that it is a programme of value that represents in visual terms what an important document would represent in paper and is therefore deserving of attention (Kilborn and Izod 1997:14).

This last point has influenced me as a writer since I place certain values on the material I am writing and want that writing to act as a vehicle into mathematics for the audience. I also hope that my audience will assimilate those same values and appreciate the nature and beauty of mathematics more highly than previously (Kilborn and Izod 1997:59). Grierson was similarly convinced that documentary could be used as a vehicle in this manner to provide cultural or, what now sounds rather condescending, educational enlightenment and this is the sense that has directed my writing in this project (Kilborn and Izod 1997: 19). Corner argues that Grierson could be seen as the bridge between two sets of ideas, that of using the documentary for its social purposes and that of explaining the intrinsic nature of the subject through its filmic practice. It is the tension between these two purposes that posed a number of problems in terms of the function or role of this project. I was constantly in danger, as a writer, of being propagandist, in writing a social–purpose film, when I really should be promotional and by that I mean writing a film that illustrated the accessibility of mathematics (Corner 1996:4).

It seems to me that the purpose of a documentary has to be both a testimony to events (cf. Winston 1995:21) and an explanation of those events and the implications of those events for future aspects of daily life (Kilborn and Izod 1997: 17). In this sense, documentary is authorial but it is also what Corner calls a vehicle for Grierson's ' agency of citizenship and reform' (Corner 1996:14). This is because of the 'referential reliability' of documentary, making it a key agent in 'modern public information' (Corner 1996:14). My intention, then, was to create a piece of documentary visual writing that is at once dramatic and fascinating and treats the actuality inherent in mathematics in an ethical manner, that is, as a topic of value to the whole community and to show that mathematics, as a subject, is clearly of value in itself.

The Creative Treatment of Actuality

What is the creative treatment of actuality and how has it developed in documentary? Brian Winston quotes Ivor Montague as suggesting that 'every work is the creative treatment of actuality. Actuality is the raw material that as experience must pass through the consciousness of the artist to become transformed by labour in accordance with technical and aesthetic laws into the art product'(Winston 1995:14). In this sense documentary goes beyond journalism and has claims of artistry and drama, which are vital components in any project (Winston 1995:10). It is this human input that creates the documentary; but this input is also an imposition of values that can be unethical. For example, Martin Bashir's depiction of the popstar Michael Jackson led to the latter's court case and the dismissal of all charges against him (Bashir 2003). The court case clearly would not have happened without the documentary. Similarly, one could mention the unethical treatment of the actor David Soul and the, as he saw it, lack of balance in the documentary of his life (BBC 16 March 2004). Certainly, as a documentary writer, it seems reasonable to suggest that one has to have an awareness of one's own value position and how it affects one's writing and ultimately the subject and people who are shown in the film.

At issue here is the creative treatment of actuality. It is the very tension of creatively manipulating actuality yet wanting it to remain as a true record of a depiction in life that has exercised the minds of academics in thinking about the documentary form. By treating actuality in a creative manner we are inevitably applying a set of values that transform the raw materials of life into a documentary (Kilborn and Izod 1997:13). Grierson himself recognised that his definition of documentary as the 'creative treatment of actuality' was clumsy but argued that it should stand, probably because no better definition was available (Winston 1995:13). Its shortcoming is that it allows unethical behaviour to be counted in some ways as legitimate.

An illuminating example of unethical behaviour that was at the time regarded as legitimate is Leni Reifensthal's *Triumph of the Will* (1935). This was a documentary about Hitler and the Nazi Party and is a piece of extreme propaganda. It has no spoken commentary and as a result the positioning of imagery in the film takes on an added importance. Verbalisation in the film is left to the speeches of Hitler and other Nazi leaders. In her directing, Riefenstahl cleverly focuses on presenting Hitler as a saviour and on the fact that people identify strongly with an individual or a leader rather than with an agenda (Johnson 2004:86). The visual presentation works by association: a set of images is presented in a manner that leads the viewer to a position desired by the Nazis, with all of the images set to music by Windt (www.imb.com).

Winston points out that the images Riefenstahl used were in many ways faked, and the overall effect is that we see Hitler make a God-like descent from the clouds. In the film, we also- see crowds standing on walls awaiting the aircraft and in front of trees though there were no trees and walls at the airport where it was supposedly shot (Winston 1995:107). Riefenstahl creates a stunning but chilling effect by her choreography of the images and the sounds (Barnouw 1993: 105). The images activate identities but also give the viewer a purchase on the search for explanations of circumstance and power (Murdock in Gripsrud 1999:14). In the same way that Riefenstahl effectively 'sold' Hitler, I had to examine my own ethical stance in that I was possibly guilty of committing the same unethical behaviour regarding mathematics.

In terms of my own ethics and ethical stance, when I started this project, one aim, as mentioned above, was the overt attempt to 'sell' the subject of mathematics to viewers. Bourdieu's assertion of television's de facto monopoly of what goes into the heads of the population would seem to be a justification to use television as a means to educate people, preferably when they are unaware that they are being educated (Bourdieu 1998:18).
At the start of the project the use of the medium seemed vital to achieving the aim of 'selling' mathematics (Kilborn and Izod 1997:233). On reflection, however, this might prove to be the same as Riefenstahl's 'selling' of Hitler, and when I realised the nature of what I was doing I had to rethink my own values and those that were going into my writing.

Although the media is the main source of information to individuals about the world beyond their immediate surroundings, the media is not a value-free zone and neither was my writing (Ontario in Yates 1999:2). My writing started with a rather basic utilitarian aim but I also came to see as, Bradford Yates points out, that the media shapes and distorts reality (Yates 2007). It was this shaping and manufacturing of reality that led me to pause; I had to reflect on my place as a writer and consider the efficacy of trying to sell mathematics. I realised, as Chomsky puts it, that 'Nobody is going to pour truth into your brain. It's something you have to work out for yourself' (Barsamian 2004).

There is, I began to see, a fundamental clash between the patriarchal worthiness of much Griersonian inspired public broadcasting, which is what I was trying to do, and the understanding of how viewers' perceptions of cultural artefacts has been shifted with the so-called the post-modernist agenda (Kilborn and Izod 1997:10). There is no doubt that in developing the new form of 'creating actuality', Grierson influenced subsequent documentarists to create films with a clear social purpose, but there is also an essential art to the documentary. In this sense my view has shifted, but not totally changed (Corner 1996:11-16). Instead of trying to persuade people as to the utilitarian benefits of mathematics it seems to me to be far more appropriate to show the beauty of the subject, the art of the subject, the sheer fascination and empowerment of the subject and its history (Kilborn and Izod 1997:119). If television documentary is not used to share something of this side of the subject, it is wasted (Bronowski 1973:14).

Charles Okigbo argues, with some force, that the effect of television on cultural development has serious implications. He notes, as an example, Ogbu Kalu's point that culture is an anchor for society, how Africa had witnessed a 'shell burst' from foreign cultures and how much of Africa's culture was imprisoned within European cultures. Evidence for this perhaps includes the early British policy of permanent settlement in Kenya that led to the import of many Asians to work on the railway. This in turn led inadvertently to an 'indelible' mark on the culture of the country and on the main contents of Kenyan television (Okigbo in Smith 1995:370).

In the same way, I would argue that television has re-enforced C.P. Snow's suggestion that Britain has two cultures, that of a scientifically (and by extension mathematically) illiterate establishment, that is predominantly arts educated, leading a society that is scientifically dependent (Snow 1998: XXV). Snow saw that it was dangerous to have two cultures that cannot or do not communicate (Snow 1998:98).

Culture and Mathematics

There are, of course, difficulties in bringing arts and sciences closer together. The popular imagination, for example, still sees the scientist as an unsympathetic figure, someone human but strange, as with Faust or Dr No or Frankenstein (Ziolkowski 1981).

I do think it is not unreasonable to suggest that the idea of the depiction in literature or television of an independent 'normal' scientist (as, for example, in *Waking the Dead,* BBC TV*)* goes against a long tradition in both literature and television and that what we read, and what we see certainly does affect our attitudes. Clearly the traditional approach to portraying science, and by extension mathematics, in literature is not desirable if we wish to persuade people to engage with these subjects. This is why the characters that figure in my writing must appear as three-dimensional human beings that the audience can relate to; it is vital that the figures involved in the history of the subject are seen to be the type of people with whom the audience can form a sympathetic bond.

Snow, writing in 1959, recounts a tale from the 1890's where people revelled in their own innumeracy (Snow 1998:3) and this attitude still has a grip on our culture, despite exhortations to the contrary (Clarke in Lawler 2006: ix-xi). Snow argued that we have two cultures where the scientific approach to knowledge is looked down on and that the classical arts-based education favoured by many of the so-called middle classes has higher status. Similarly, Will Hutton has argued that the country has made ' no systematic attempt to train a class of officials competent in commerce and finance' (Hutton 1995:53).

Against this cultural background, it is, of course, totally unrealistic to expect to begin a sea change within our culture from one television series. Hutton also says that television's mission to educate and inform is in decline, but there is some evidence that such cultural changes occasionally happen as a result of documentary (Hutton 1995:40). For example, in Roger Graef's *Complaint of Rape* in the Police Series for BBC Television 1982, the police were seen dealing with a female rape victim in a highly insensitive manner and the public outcry from this documentary led directly to changes in police interviewing procedures (Kilborn and Izod 1997:237). It is interesting that the projected spectator position in *Complaint* was from behind the female complainant, largely to protect anonymity (Corner 1996:50). But the effect of this was to experience the insensitivity as if we, the viewing public, were actually in the position of the young woman. One cannot help but wonder what the dynamics of the programme would have been had the camera been mid-way between the woman and the police, with the woman in darkness, and what sort of effect there might have been on the experience of viewers (cf. Kilborn and Izod 1997:237). One key question that I have which remains unanswered, however, is was the public outcry occasioned because the young woman was verbally violated after clearly having been physically violated, or was it because we, the audience, were also verbally violated by reason of the positioning of the camera?

One can ask similar questions regarding changing the attitude of the public as a result of the legal reconstructions that occur in documentary series like *Trial and Error* and *Rough Justice*, which have both raised the publics awareness of miscarriages of justice, or as in Edward Murrow's *Harvest of Shame* which shocked Americans in 1960, with its depiction of the treatment of migrants (Rodham-Clinton 2004:48). Indeed, Frederick Wiseman suggests that 'documentaries are thought to have the same relation to social change as penicillin to syphilis' (Kilborn and Izod 1997:238). However, in reality, the importance of documentaries as political instruments of social change is not easy to prove because of the absence of any supporting evidence, and partly because there is a plethora of other information sources from which the audience can acquire information.

Values affect the choice of words, the selection of images and the structure of an argument in documentary, but to expect a paradigm shift in cultural attitudes simply as a result of a documentary is unrealistic. Where such a change in attitude occurs it is a rare exception. At the same time, the writer has to remain conscious of the kind of presentation to be made in a documentary and the implications of the creative treatment that one applies to the actuality, remaining constantly aware this is not a value-free zone and may have a considerable impact on the meaning that is constructed by the viewing audience. This was made clear in the case of the Zapruder Film.

The Zapruder Film

The Zapruder Film has become legendary in documentary history as a benchmark of supposedly value-free documentary (Ward 2005:8). On the 22 November 1963 in Deeley Plaza, Dallas, Abraham Zapruder recorded the Kennedy assassination. Zapruder, as a filmmaker, was merely recording events. Apparently he had no intention of creating a documentary. In terms of the mediation process, as Bruzzi says, 'The underpinning issue of documentary film is whether or not the intervention of the filmmaker and therefore the human eye renders irretrievable the original meaning of the events being recorded' (Bruzzi 2000:13). Zapruder apparently did not film with a conscious set of values; he was just recording an event and seems to have been in a non-critical position. But he was a medium through which the event was recorded, and his film cannot be regarded as a value-free zone. Bruzzi makes the point that the film's value is precisely because there was no pre-meditation, intention or authorship to it (Bruzzi 2000:14). But there clearly was an intention to film on Zapruder's part, since he returned to his home for the camera he had forgotten and chose the best location from which to shot the film (Bruzzi 2000:13). Zapruder himself stated:

> 'I got out in, uh, about a half-hour earlier to get a good spot to shoot some pictures. And I found a spot, one of these concrete blocks they have down near that park, near the underpass.'
>
> (ABC Transcript 2006)

These comments clearly show pre-meditation, or intention, or even a kind of authorship on Zapruder's part. It is clear that he deliberately went back for the camera and then, as the quotation above shows, made choices on how he was going to construct the images. In effect, he treated the actuality creatively. Bruzzi goes on to argue that 'The Zapruder film, as a piece of evidence has severe limitations', and proposes two levels of truth: 'the factual images we see and the truth to be extrapolated from them' (Bruzzi 2000:16). Certainly the film has proven to be a great harvest for conspiracy theorists, raising doubts about whether we can believe what we see on film or television. One further effect of the Zapruder film was that the term 'Zapruder' was to become an adjective for supposedly value-free representations, but the truth is that whenever we represent something in the media, its reality comes into question. Indeed, Britton points out that 'there is no such thing as a representation of the world which does not embody a set of values' (in Bruzzi 2000:14).

This is also the case with the depiction of other subjects in the media, including the seemingly objective subject of mathematics. In all cultures ideas operate in historical settings and to challenge those ideas is to challenge the status quo (Collini in Snow 1993:lxx). Peter Lancaster puts it succinctly: 'in any country, the place of mathematics in society depends on the nature of the society and its ambitions' (Lancaster: 2007).

Snow's seminal work in *Two Cultures* recognised that there has always been a class-based prejudice against mathematics during the twentieth century (Snow 1993:4). We respond to science and mathematics in general by the values we hold. In the past we have lived with the culture of knowledge scarcity, but this is no longer sustainable, if it ever was (Burke 2006). In the twenty-first century, advanced societies will depend on the capabilities of their people as intellectual capital assets rather than on their labour as capital assets. Knowledge scarcity has become, via the use of information technology, knowledge abundance. However, the ability to apply knowledge in problem-solving situations is an intellectual application that is the result of higher-level thinking. By higher-level thinking I mean the ability to consider reality, abstract it and manipulate symbols to find a solution to a problem or situation and then reapply the solution from the model to the real world. This level of thinking within mathematics is called modelling and this is at the heart of the subject and also the reason why, as a subject, mathematics is so important to both the individual on a personal level and the nation state as a whole (Reich 1991:177). Nevertheless, the subject for all its importance still remains challenging to both the writer and the filmmaker of documentary, including the question of reality.

Depicting Reality

It is important to recognise in making documentaries that the concept of reality and its depiction is fraught with difficulty. The role of the filmmaker is to act creatively on the actuality recorded and present it in an ethical manner that will enhance the meaning of the narration, with its interaction with imagery. It is this attention to the detail of one's values that made me reflect on the earlier mentioned aim of seeming to propagandise the history of mathematics as the objective of this project. By writing in the style I have chosen, I have deliberately steered the viewer towards the people within the history of the subject rather than the matter itself. As a writing technique this is justifiable since it enables me to engage the viewer, but is it ethical? Dean Koontz argues that every turn and twist of the plot of a novel should be filtered through the unique personality of the author (Koontz 1981:57). That may be acceptable for novels but it does have a different impact on writing non-fiction and in depicting what Brian Winston calls the real (Winston 1995:13).

Without consciously realising it, I had previously adopted a set of Griersonian values as a writer, namely the ethos of paternalism that informs the tradition of public-service broadcasting (Murdock in Gripsrud 1999:14). It was, however, increasingly necessary for me as an author to reframe the motivation for writing my project. The danger was that my conscious attempts at the representation of reality meant that the integrity of that reality was (as Eric Barnouw asserts but Bruzzi dismisses as erroneous) in danger of being lost (Bruzzi 2000:4). In the end there was perhaps no way out of this dilemma.

My representation of the actuality is in my writing of narrative, my writing of speech for historical characters and in selection of images to support the narration and acting. All of these filter out any kind of raw reality but also enable me to try and bridge the gap between the two cultures as described by Snow while staying true to the (sometimes contradictory) Grierson tradition of making documentary into art.

The Art of the Documentary

The Griersonian tradition established the documentary as an art form and suggests that the pursuit of documentary is the pursuit of art for the sake of art and no other (Winston 1995:24-5). This establishment of the status of the documentarist as artist was crucial because, as Winston points, out it was based on the nineteenth-century realist tradition which meant that the duty of care to others while making films was 'attenuated'. The art became more important than the people represented by the art and, as such, should anything untoward happen to those represented in this manner, well, that was just unfortunate (Winston 1995:24).

For the Griersonians, the claim of the documentary as an artistic enterprise with serious implications for social betterment was imperative because it was, according to Linda Nochlin, how art in general was deemed to function in the nineteenth century (Winston 1995:26). Early documentary practice in this tradition was essentially an artistic representation of the reality of the time. Paul Rotha argued that documentary 'must be the voice of the people speaking from the homes and the factories and the fields of the people' (Winston 1995:27). Similarly, Grierson argued that 'the documentary idea demands no more than the affairs of our time shall be brought to the screen in a fashion which strikes the imagination and makes observation a little richer than it was' (Winston 1995:28). In this sense my project sits well in that the Griersonians saw the function of art to be social (Proudhon in Winston 1995:30). In the same way I want to use documentary as an art form for what I regard as social enhancement so that viewers can re-deploy their frames of reference when making sense of their own social world (Kilborn and Izod 1997:41). In particular, this project aims to change the way mathematics is viewed, almost quite literally. Instead of seeing it merely in terms of numbers and themes, it will, I hope, be seen as a living subject full of images, people and events.

Styles of Documentary

Nichols defines six different types of documentary which he calls poetic, expository, participatory, observational, reflexive and performative. He describes these modes as a 'loose framework of affiliation' and then goes on to suggest a kind of neo-Darwinian evolution in the development of these modes from X to Y (Nichols 2001: 99). Ohayon, however, likens trying to categorise documentaries to 'eating jello with chopsticks: the films keep sliding out of the categories you set up', and this may be part of their attraction (Ohayon 2006). My project contains elements from more than one mode, namely expository and performative, and this is deliberate on my part since I am trying to create something new. As Ohayon puts it, 'expository documentaries are what most people think of when they think of documentaries', and it makes good artistic and commercial sense to write something based in this mode (Ohayon 2006). To be perceived as good writing, however, the programmes need to be visually interesting and contain a topic that is set out and expanded in some detail. In that sense they provide a visual argument that in its component parts attracts and entertains viewers but also informs and engrosses them in the subjects. To this extent documentaries employ and exploit drama and its techniques.

Drama in Documentary

Drama in documentary is a fundamental component that audiences are now used to seeing, as a vehicle for the representation of actual events, particularly from history. This is especially important in the reconstruction of events, as, for example, in the case of *Who Bombed Birmingham*? (Beckham1990) or for the regular crime reconstruction programmes such as *Crimewatch* on BBC television (Kilborn and Izod 1997:157). This style of programme forms what Corner calls a 'distinctive kind of experiential action-related testimony' of the events they reconstruct (Corner in Gripsrud 1999:180). It is a mode that constructs a film around an often hidden aspect of performance but there are ground-rules, which the audience will expect to be obeyed (Bruzzi 2000:153). David Boulton (in Rosenthal 2002:278) sums up Woodhead's rules for creating drama documentary as:

> no invented characters;
>
> no invented names;
>
> no dramatic devices owing more to the writer's (or director) creative imagination than to the impeccable record of what actually happened.

Leslie Woodhead is also quite clear that for people in the television documentary industry, the dramatised documentary is an exercise in journalism, not dramatic art (Rosenthal 2002:278). Nevertheless, the exercise does remain 'dramatic' both by its topics and by the use of human figures to act out a scene based on real events.

There is a link between the type of programmes I have written and dramas that adopt the style of a documentary as, for example, *Cathy Come Home* by Ken Loach, where the actors improvise their lines. Loach's film had such a realist aesthetic that the performance that occurred between the actors drew the audience into the reality of the situation being fictionalised (Bruzzi 2000:153). In *Enigma Variations* where I explore the tension being felt by Elizabeth over the need to sign the death warrant on Mary Queen of Scots, I have deliberately written it as a dramatised reconstruction of events that did actually happen. In the sense that this is drama I have had to create lines for both Elizabeth and Walsingham and had to show the emotional impact of the decision on the Queen, seen in the last sentence when she says to Walsingham:

> 'and when they have cut off the head of one Queen my Lord, how much easier it becomes to cut off the head of another'.

The line shows a personal dilemma for the Queen, and by suggesting there is a personal risk involved I hope, as the writer, that this then creates an emotional response in the viewer because it is both describing and performing an action that happened in history. As Bruzzi notes, 'the pre-requisite of performative documentary is the inclusion of a notable performance component into a non-fiction context', as with Elizabeth and Walsingham (Bruzzi 2000:154). It is, however, obviously impossible actually to represent the meeting or the true nature of exchanges between the Queen and Walsingham, even though they are available in the historical record as a summary of events (Singh 1999:3). In reality, however, there is no known transcript of such meetings (Sandford in Rosenthal 2002:278). Drama, therefore, in this context, or more strictly dramatic writing in a script, is both a substitute for and an interpretation of history.

The effect of using drama in this scene is intended to create convincing 'visual evidence' (Hampe 1997:69). This 'visual evidence' is then used to carry the weight of the argument for the viewer (cf. Kilborn and Izod 1997:139). In particular, it was important for the viewer to see that the verisimilitude, the appearance of reality or truth in the scene, is a question of showing the nature of the dilemma for the Queen (see Becker 1998). In my view, and this is my creative treatment of the historical actuality, Elizabeth's dilemma was not because Mary was a blood relative but rather the matter of the preservation of Elizabeth herself on the throne. Modern-day viewers' cultural context is, of course, not the same as that of those who lived in Elizabethan England. In this sense the verisimilitude in the scene must do nothing to suspend the audience's willing suspension of disbelief (Hampe 1997:71). The scene works because it is a realistic scene that represents the 'accommodation' or perceived values of the audience who are watching (Kilborn and Izod 1997:39). When this happens, we as viewers accept as real the fictional drama we are seeing on the screen.

Indeed, Becker argues that audiences accept verisimilitude in fiction without a problem

(Becker 1998). He cites the absurdity of the relationship between the two main characters in James Cameron's 20th Century Fox film (1997), *Titanic*. We accept this as an example of verisimilitude because it fits within our societal values: we want the characters to meet and fall in love but the female character was supposedly an upper-class English woman while the male character was steerage-class American. In reality this relationship is unlikely to have happened, but we allow ourselves to believe in the realism of the scenes we see on the screen. Such acceptance of verisimilitude would not be acceptable in documentary, but documentary does allow us to drop out of narration and into a dramatic scene and then back into narration without losing viewer interest and thus justifying its place as a writing technique in the project.[1]

Similarly, there is accommodation in the technique of having the character talk to an unseen interviewer off screen, another form of drama in my project. Foucault argues that the interview is a regulated form of exchange with the power distribution being uneven between the client and the interviewer and therefore it makes sense to write such scenes as if they were monologues (Nichols 2001:122). We see them as if the sound of the interviewer's voice has been edited out and the character is responding to a question without us having heard the question. This was necessary in order to ensure that the audience response to the characters was to treat them as people who are important to the story and not as subordinate to the interviewer. It also means that the story flows with a greater rhythm. This style of presentation where I am trying to make the writing flow by using monologue is clearly an artistic decision and one that others may disagree with, but this to me is the central role of the writer, to create an interpretation of reality that is dramatic, informative and entertaining.

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[1] For a fuller discussion on narration, see the appendix, 'Narration'.

CHAPTER TWO

Making Documentaries

Introduction

When starting to write the programmes in this series I made a conscious effort to replicate the type of experience that most viewers will have had as children, namely that mathematics is split into number, algebra, shape and space, data handling and also using and applying mathematics. Therefore I devised an outline strategy that the five stories to be told would involve an investigation into numbers, then a trip into showing how the study of shape would be of interest. However, I did think that a programme on algebra would prove boring, since for most people this does seem to be an indecipherable subject. Instead I decided to focus on codes, thereby bringing some algebra into the programme, albeit within a context. Finally, the thought of a programme on data handling was dreary. It therefore seems to be far more sensible to show mathematics within its role as a predictor of uncertainty. The broad outline became thus became:

- *The Dawn of Nothing*: how numbers developed and how we use them now in everyday life;
- *On Earth as it is in Heaven*: how people developed earthly representations of what they saw in the stars;
- *Enigma Variations*: the story of codes and coding as used throughout history;
- *In the Footsteps of Euclid*: aspects of the story of geometry;
- *The Measurement of Uncertainty*: probability.

This gave, what I believe, is a good basic overview of the subject.

The importance of titles

When writing the individual programmes it was important to create a unique title for each programme. This is not quite so important when I am writing a mathematics book for students, but when I am writing for a wider target audience the title has to intrigue and fulfil two roles. In a sense the title is a hook that draws the viewer into the programme. The overall title of the series, *The Language of the Universe,* is meant to attract interest and raise questions. What is the language that is universal across the universe and beyond? The answer has to be mathematics. Regardless of where you are in the known universe, every planet obeys the same laws, and those laws are both simple and mathematical.

In my book writing I also always aim to try to have a main title and a sub-title. The main title draws the attention of the purchaser whilst the sub-title aims to provide a benefit that will persuade them to buy the book. In naming the programmes in this series I have used the same process. The programme title also needs to carry some evidence of meaning in the sense that there has to be some reference to the actual programme content. So it is that Programme One, by being called *The Dawn of Nothing,* acts in the role of being an intriguing title. Hopefully this will encourage the viewer to want to know more about the subject, and to reflect on the fact that, in the story of mathematics, the development of zero or nothing is fundamental. It is a simple yet wonderfully powerful development in thinking that allowed people to manipulate figures intellectually. The title for Programme Two follows a similar pattern; again it functions as a sub-title for the series and as a source of intrigue for the viewer. It is also a reference to the line in the Christian Lord's prayer and therefore will also have resonance with a large section of the population (Kilborn and Izod1997: 39). *Enigma Variations,* Programme Three, is a play on the Enigma code machine from World War 2 and the number of variations that were possible, whilst the title for *In the footsteps of Euclid* is meant to suggest journeys ahead. Finally *The Measurement of Uncertainty* is again written to provoke curiosity.

Having established themes for each programme, it became essential to find stories that linked through the theme as well as a model that would inform the writing.

The Writing Model

My project is based on a writing model created by James Burke with his now famous *Connections* series from 1978. Here Burke created what he called an alternative model of change in which historical events were linked and led to outcomes that the viewer can recognise. Burke described this model initially as a ring (Burke 1978) but in later years went on to refine the model into his now famous web (Burke 1996: 3-5). The ring represents a circle of knowledge where one enters the circle and finds a myriad of different avenues that wrap around the circle in various ways. Finally, one emerges from the circle to join exactly to the point where the journey began. This is simply not sustainable in academic terms but it does work in terms of presenting knowledge for entertainment purposes.

Burke's ring is a simplified version of actor-network theory. Michel Serres and Bruno Latour argued that actor-network theory was the study of 'heterogeneous engineering'. By 'heterogeneous' they mean a 'multiplicity of different connections' and they use the term 'engineering' because these connections were seen to have been 'fabricated out of a diverse range of materials' (Johnstone et al, 2000:4). This means that actor-network theory is based on four main principles. The usual boundaries from and within which western knowledge is constituted, that is, between people and objects, 'nature and culture', ' tradition and modernity', need to be put aside (Johnstone et al 2000: 5). They argue that these form divisions within 'associations'. The argument is that it is the links rather than the nodes of the network that are the more important. The network is made, or constituted in, 'the passing' from one node to another.

The second factor is circulation. This relies on what have been called a whole series of 'immutable mobiles' (Johnstone et al 2000:5). In other words, these 'transportables' are defined as anything that can be transported from one location to another without changing form. Knowledge, although essentially a human construction designed to aid understanding, in fact, it is argued, obscures the real nature of the world. Actor-network theory says that the world is a collection of heterogeneous activities which are constantly in formation (Johnstone et al 2000:5).

The fourth and last principle is a result of the previous three. This lays stress on ' mediaries' and 'intermediaries'. This suggests that the 'messages' that are conveyed along the networks are the most important element since they keep the network together and keep it moving into other networks.

This seems to me to close to the underlying theoretical explanation of the reality behind Burke's model of knowledge. The weakness in Burke's model in relation to actor-network theory is that it is a two-dimensional version. The ring or web of knowledge model that he proposes allows for lateral transfer of knowledge, in terms of connections between apparently disparate but connected things, but does little for the vertical development of knowledge. By vertical development, I mean the increasing complexity of knowledge as new knowledge is discovered and layered on older knowledge. Burke's may be acceptable as a vehicle for creating entertainment but it is not a good model for knowledge acquisition and development. Rather than this two-dimensional version of knowledge (which is by definition unorthodox since the model is dependent on coming back to the starting point), I regard knowledge acquisition as a three-dimensional actor network, in which new knowledge is based on what has been previously discovered both vertically and horizontally.

In fairness to Burke, as I have mentioned earlier, his model has been modified over time to suggest that rather than a ring, knowledge is a web and that there are multiple interrelationships Again, in fairness to Burke, he has developed this approach to be more academic based on his web (Burke 1999). This more clearly represents the actual developmental process, where knowledge is built and developed on the 'shoulders of' previous knowledge (Bragg 1998:97). I do not intend to get into the debate whether knowledge is discovered or created since this is an area of epistemological study in its own right and takes us away from the development of the project. However, I would say that, the first stage in development is to write the television series so that it both intrigues the viewer and creates awareness of an issue or a concept. This is the lowest rung in the model. If there is no awareness, there is no need to acquire knowledge and develop as a society. A good example of this is shown in Programme One where we discuss the fact that the Native American tribes never developed concepts for numbers simply because they did not have to. The need to intrigue in the programmes is vital in the acquisition of knowledge and has to be written into the first stage of the series, since without it there is no motive for the viewer to continue watching.

The second stage is to revise. Each programme was initially written in the style that is common in television- namely the original script was written with a description of what would be seen in the image. For the purposes of the university and this course it was decided to source typical images that would give an indication to what the viewer would see. This would not be the case in a script that was submitted to a television production company but, as I have previously mentioned in chapter one, it does give the reader an indication of what s/he would see were this to be made into a documentary series.

The construction of meaning from images

As Kilborn and Izod suggest, ' every aspect of...style is designed to persuade us that the film makers were there, and that (by) viewing the historical world through transparent and referential indexical images, we have shared that experience' (Kilborn and Izod 1997: 37). There is thus created a shared understanding between the viewer and producer where, for example, the use of historical re-enactment is used to both entertain and to convey meaning. Lakoff calls this functional embodiment. It is, he argues, the notion that certain concepts are not merely understood intellectually but they are used automatically, that is without noticeable effort as part of normal functioning (Lakoff 1987:12). We 'learn' to watch documentary by acquiring a functional embodiment of the values and cues that indicate a documentary is something of substance. Thus when Ricky Gervais uses the same techniques in the comedy *The Office*, some viewers actually believe it to be a documentary rather than a 'mock-umentary' (Barbazon 2005).

Cameras and word processors are sometimes at odds with each other simply because filmmakers create with images and writers create with words. It is often easier to understand words than a sequence of images, if only because most times words carry shared defined meaning whereas images are open to interpretation by the individual. But the point that needs to be clear is that it is the images that make the documentary. A script that is over long can be dull and talky, whereas a documentary that is showcased with a series of vibrant images can captivate an audience (Hampe 1997:136). Therefore it is the case that writing a script means thinking in pictures. In effect this is an essential step as a writer: one has mentally to put oneself in the seat at a cinema and look at a screen rather than in front of a word processor. Hampe suggests that the hardest thing for a writer beginning to work in documentary is to stop relying on words; as he puts it, ' If you can't see it, you can't film it' (Hampe 1997:140).

'Kino-Eye,' according to Vertov, is 'the documentary cinematic decoding of both the visible world and that which is invisible to the naked eye' (Beller 1999:154). Beller goes on to suggest that what we learn from Vertov is that the image is constituted like an object: it is assembled piece-by-piece like a commodity moving through the intervals of production and it is a (technological and economic) development of the relations of production (Beller 1999:162). In writing this project, I have used images to assemble meaning 'piece-by-piece like a commodity moving through the intervals of production', to create a product that will go on to further realisation in film or video.

Hampe sums up the above in the following way:

> A documentary is made to communicate to an audience; a documentary communicates through strong visual images organised in sequence to make a statement; visual images can only be described with concrete nouns and action verbs; editing is at the heart of the process in a documentary. It's the documentary you show; not the footage you shot, that counts.
>
> (Hampe 1997:53).

The very nature of my project means that it is an exposition of a series of interlacing concepts.

Watson's advice, however, of never writing more than ' 30 words, that's 10 seconds' is at best, it seems to me, naive and not likely to lead to a sustained series of strong programmes (Baker 2006:70). Nor will it lead to a good story and that is necessary for attention to be held (Winston 2006:128).

Good stories never go out of fashion and, as Barthes, suggests stories are a cultural universal (Castro 2000: 23). Kelliher et al (2003) go on to state that documentaries are a particular type of story that:

> explore real world events in primarily an audio visual form and that conventional documentaries convey one or more narrative threads.

The performer Ruby Wax is also a highly successful documentary maker and describes the creation of the documentary as a journey (James 2007). In these comments there is ample suggestion that authored documentary is a modern development of the centuries old tradition of storytelling. Aristotle defined storytelling as the art which gives us a shareable world, this is exactly what my project is designed to do, to tell stories that 'give us a shareable world' (Kelliher 2003:3), but in images as well as words.

From idea to first draft

In writing stories I first of all look for events that demonstrate what people have done and how they can be linked. This is effectively character-driven plotting of a story. By character I mean ' the sum total of the qualities that make one man or woman different from the next' (Kelsey 1990:105). There is much debate in the creative writing world of what comes first, character or plot. Andre Jute is adamant that plot is driven by character and that writing which is plot-based first and then populated by characters to lead through that plot means the writing is wooden and the characters are two-dimensional (Jute 1990:96-97). Michael Legat is not as convinced, but gives a somewhat rambling explanation as to why plot matters (Legat 1992:18). Marina Oliver gives a far better explanation when she says that character and plot are interdependent and that 'characters must be appropriate' (Oliver 2005:33). Koontz agrees, and although he is talking about novels, what he has said can be applied to documentary: ' You cannot pretend that plot is less important than other elements in a novel's construction' (Koontz1981: 56).

Although my writing in this project concerns real people from history, I needed to invent a character for many of them or represent them as a character that is faithful to the historical accounts of them as people, but I also needed that character to develop within the plot of the story I am telling. Kelsey points out that people reveal their character in their temperament, behaviour, attitudes and prejudices; he goes on to say that a person's character is ' born of the many different factors we inherit and the pressures and influences of our own particular upbringing and surroundings. It may be expressed through the way a person dresses, the kind of home they choose to live in, the sort of friends they make, through their hobbies, through the way they speak, the words they use and by no means least the tone of voice. It is through speech and actions that character is portrayed' (Kelsey1990: 105). It is this last sentence that is the most important: character informs behaviour and it is this that drives the plot forward in the way that Oliver's assertion of the interdependence of the two proposes.

Plot is not merely a chain or list of events but a description of why people do things (Jute 1992: 68). This also has to be true for good television. Viewers watch television to experience the emotions that the characters experience, not simply to watch characters experiencing those emotions (Kilborn and Izod 1997:9). Writing as well as being a craft must also be considered an art and this requires an emotional involvement on the part of the writer. By this I mean it involves a deep commitment on the writer's part and the writer should write about things that concern him and create and write about characters that appeal (Koontz 1981:57). It is this emotional involvement by the writer that creates rounded characters who add real emotional depth to the writing, so that the audience begins to be involved with the writing, the characters and their situation.

This is why in Programme One I have written scenes where the motivation for action is obvious, as for example, in Babbage's wish when referring to the correction of logarithm tables, 'tis a pity this cannot be done by steam'. This sets out his reason to go on and develop his various machines that were early calculating devices and it is in identifying this desire in the character that the professional writer makes that character attractive to the reader/viewer (Kilborn and Izod 1997:9). At the same time, in writing for television, one does have to be aware that the effect of media is to create a spotlight on those it portrays. Where there is shallow characterisation or a lack of real plot, even in reality/non -fiction programming, the spotlight is turned back on the writer and the production team (Kelsey 1990:107); one only needs to recall the furore of Channel 4's *Big Brother* racism row early in 2007 to see how vitriolic this can be.

If the first step in writing is the consideration of plot and character, the next step has to be how to shape the film as a logical and emotional whole (Rosenthal 2002:59). In writing this series I had to decide between a tele-visual essay and a narrative (Kilborn and Izod 1997:9). By narrative I mean a totally encompassed story that contains characters, drama, conflict and can attract the audience in meaningful ways. As mentioned above, viewers watch documentaries to engage with the characters portrayed and to experience the same emotions that the characters are experiencing or alternatively through sheer horror and fascination, as for example when reviewing Jane Sayers' film *Welcome To Potters Bar: A Rail Cops Special - The Victims Stories.* Martin James commented that;

"Jane Sayers' polished and moving film coveys the story vividly and generates a range of feelings including sorrow, anger, sympathy and admiration..."

(James 2006)

The film works because of the development of the story involves the viewers' empathy with the victims of the accident but also because the film has a completeness about it that increases its impact.

Research and planning

It may sound obvious but good images in documentaries do not come out of the air. They have to be planned for as a first stage, and this was the approach I used in planning for the initial draft of the programmes. Planning to make a documentary is the same as building a model: it is the creation of a model of an event (Hampe1997: 121). With this in mind I set about researching the stories that make up the project but in a way that always had an emphasis on the visual. The constant question in writing this type of series is, 'How will it look on the screen?' Researching the facts is not enough; one has to have an understanding of the relationship between the facts and what will be shown to the audience.

The visual evidence in the documentary has to be presented as images that the audience sees and experiences, and the images must be powerful and unarguable (Hampe1997: 122). This is why I have chosen to use interviews in the writing rather than relying just on narration. Some narration to explain facts is essential, and that is why, in the case of Andrew Wylie (Programme

Four, *In the Footsteps of Euclid)* I have done exactly that, but it can be dry. An interview is, or should be, a relatively spontaneous event that is more or less unrehearsed dialogue. Interviews can be done to show the person on camera as an expert and to offer, for example, a witness to an event (Hampe1997: 264). However, as I have mentioned elsewhere, there are times when a practical decision has to be made regarding the writing and one has to conclude that many people watch documentaries largely for entertainment. Therefore, whilst it is important to have the presentation of factual information, there is also a need for entertainment. For example, at the start of Programme Two, I have written a piece that shows Clowdisely Shovell hanging a sailor before the now infamous Scilly wrecking. I then went on to describe the reported incidents on the beach that are now part of folklore. In researching this point I contacted the Museum on the Scilly Isles only to be told that this was a fiction created by Robert Maybe, a nineteenth- century Salonian poet. However, as material, it is rich in drama and the images that one can create are so vivid that, whilst it may not be historically 100% accurate, it was too rich in dramatic potential to ignore. As a writer there is a need to be ethical and I therefore have questioned the legitimacy of the story, and in scene 16 I have made it clear that what is fact and is true is that the ships were raided.

<u>Organisation</u>

Organising a structure for the documentary is one of the most important and, according to Hampe (1997:123), least understood aspects of production. He argues that bad structure is worse than bad writing, bad cinematography or bad acting, and that it can lose an audience. There are examples in my project where I have had to stop the story and go to another place in history to explain what is happening. For example, again in Programme Two, at scene 54, I have deliberately stopped the story and gone back in time. By writing it this way, I aim to ensure that the narrative caries the audience to the conflict between Galileo and Rome far faster than if I had written the antecedents of Copernicus first. In my view this is a legitimate dramatic device in telling the story because it keeps the audience informed and interested. Hampe suggests (1997: 123) that whilst a documentary does not have the usual three-act structure that one would expect in a play or a feature film, he is quite clear that a documentary does have the same structural need and that is to keep the audience interested from the beginning through what he calls the long development of the middle to the resolution and closure at the end. Bruce Olsen explains these points in what is possibly an ironic manner as:

> the beginning is the point in your work before which nothing further needs to be said,
> the end is the point beyond which nothing further needs to be said, and
> the middle runs between them (in Hampe 1997:123).

It is obviously important that the beginning states the theme of the documentary. This is why in all of the films I have written the beginning starts with a quick succession of images that I hope raise a query in the audience's mind. It is essential to gain their interest and keep it throughout the documentary. This is also where I seek to weave in a brief presentation of the theme of the documentary, the problem it deals with, the main people involved and whatever the audience needs to know for the documentary to move forward.

In writing a series like this, one needs to let the information come in when needed. The middle part of the documentary is the presentation of evidence in favour of the argument. This is where the conflicting elements of the situation are explored by showing visual evidence in support of and in opposition to the theme. The purpose of this is to produce something like dramatic conflict into the film (Hampe 1997:124). In Programme Two, I have shown an example of this as the Julius Caesar speech, where he reports:

> Cleopatra had recognised the need for an accurate time keeping device yea she even decreed it. I could not be outdone by a mere woman so I devised a plan to shall we say, interpret her understanding. I spoke at great length to many of her most ardent scholars and thence determined that in Egypt the year is (PAUSE) 365 days

There is a hint of danger in Caesar's plotting, designed to keep the audience watching. It is this that Hampe describes as 'structural tension' (Hampe 1997:124) and it is this 'structural tension' that also keeps the end of the documentary in doubt and creates a kind of suspense.

Creating a first draft

The first draft of the current project started with the idea of using the opening of each programme to 'hook' the viewer. This is a common device in making a documentary. For instance, James Burke hooks his viewer in one programme with a series of questions designed to intrigue:

> What do the Hubble Space Telescope, Buffalo Bill, and the Spanish Inquisition have in common? How do margarine's strange origins tie it to plankton shells, receding stars, hot chocolate, and the first solo Atlantic flight? (Burke 1999)

This is written to make the viewer wonder how Burke is going to link all of these apparently disparate items and provides the structural tension alluded to by Hampe and mentioned above. In terms of writing it is important to understand that Burke writes for his own programmes and since he is a personality his audience comes with an expectation that his writing and performing will show something of his personality which comes out through his performance in the programmes, thus giving the viewer entertainment first and then some education (Vaughan 1999:30).

When writing my project, since I am not a celebrity, I had to write for a different presenter persona. Given that this project was to be broadcast, it would mean that it would be voiced-over, probably by an actor, and therefore the writing style had in a sense to be classic. By this I mean it has to be timeless and gender neutral because it has to appeal to all ages and both genders. And the links become what Burke himself calls 'triggers' and what Jute calls his 'chain of motivation,' (Jute 1992:80).

These triggers connect one event to another. So, for instance, in *The Dawn of Nothing* I have written about how the development of Arabic numerals by Ancient Hindu mathematicians was a trigger to improve commerce in Europe. This then leads to Napier developing logarithms and on to the King's doctor visiting Norway to collect James 1's new wife where he meets Brahe and Kepler. Here Kepler (depending on which version of history you believe, some say Kepler taught Craig, others that Craig taught Kepler) learns about this new invention and uses it to develop his laws of planetary motion which influences Newton and his work on forces. This then takes us to Babbage and Herschel needing to correct errors in log tables whilst at Cambridge, which leads Babbage to utter the famous phrase ' tis a pity these cannot be done by steam'. He then goes on to develop a calculating machine and meets Ada Lovelace, the daughter of Byron. She writes a sequence of instructions for the machine and becomes the world's first ever computer programmer. In turn this takes us to the present day where we look at security on the internet, which is based on the properties of prime numbers and to the fact that Ada is now a name given to a US military computer language. The Burke model of triggers in use here works in the sense that it generates links to other stories in history. The triggers give logic to the story.

The emphasis in my project is on social and technological change rather than the mathematical abstractions commonly found in many books. The objective of the style of writing is, therefore, to provide a cultural background that is often lacking in traditional mathematics teaching. The objective in Burke's work is to entertain first (Burke 1999). But his programmes are written as 'authored' programmes rather than the traditional 'balanced' view that is needed in most documentaries in order to achieve so-called objectivity (Baker 2006:237). This style is important since it enables the story to be told in the sense that events are casually connected and that subsequent events in the story, whilst not obvious at the time, should seem inevitable once they have happened (Lawrence and Thomas 1999:1). These stories form the basis of the plot, and they define character and the structure or narrative of the documentary. All these points have to be borne in mind in creating the first draft to ensure that the viewer, once 'hooked' by the opening, sustains interest in what is, for many, a difficult science subject.

Looking for Links

One of the problems in writing this series has been to find links that both logically move the story on but also prevent taking the audience in too deeply into the actual mathematics. It is a tension that the writing has to show the story and create interest without, that is, turning the series into an undergraduate thesis in mathematics. In this sense the act of creating the series involves aesthetic and practical skills. As a writer I am satisfied even if the response of the audience is negative to the series rather (although a positive response is better) than no response at all. This is because, as a writer, I view a negative response as a position where the viewers have engaged with the writing. They have not had the positive experience that I wanted but they have engaged and therefore I have achieved something. Where there is no response, where the apathy is endemic, the writing has not managed to engage the emotions of the viewer and consequently has failed.

Choosing the place to drop out of a story and pick up another thread involves a number of decisions concerning how to link my main subjects of mathematics to historical events. The format for all of the programmes is to find a chain of motivation that forges connections characters and to develop this chain. In writing *Connections* Burke flits from scene to scene, but my series demands more from the viewer in terms of longer scenes. However, Burke's writing style is dependent on him being in many, if not all, of the shots, whereas I am writing for a disembodied narrator. This requires a modicum of restraint and Nichols (2005:18) argues that this approach has little contemporary currency except for television news, game and talk shows, ads and what he calls documentary specials. One could argue rather pedantically that all documentary programmes are special but the point is this approach does carry a semblance of authority. Whilst I do not want the films I have written to sound like Grierson's *Night Train,* I do feel that a mixture of presenter-led pieces to camera mixed with authoritative voice over is contemporary and provides a useful way of linking the themes stylistically.

One thing I do wish to talk about is the emotion of writing. This is not easy for one whose background is mathematics and science. However, David Greenslade's comment about how, when he writes poems, he differentiates between the state of being a writer with a vague idea, to one who is writing with 'applied practice' when the words are on paper, resonates with me (*Cambrian Country* 2001). As a writer I feel the idea is vague until it is written down. It then becomes a question of moulding and shaping the writing that I see as the equivalence to the jug made out of clay by a potter. This act of shaping the words is what we have referred to as Grierson's ' creative actuality'; it is my perception, as the writer, of what the overall shape should and can be like when finished. John Braine uses a similar analogy when talking about his room which he likens to a workshop (Braine 1974:9). This analogy works of for me in the sense that I see writing as much as work as art. As a published writer I believe I have more books in me, and certainly more documentary ideas, but the point here is that all of my writing involves emotional commitment. Koontz defines emotional commitment as writing about things that are of concern to the writer (Koontz 1981:57). But being professional must mean that one regards the job that has to be done with a professional eye. As Dorothea Brande puts it, this is the artisan at work (Brande 1981: 39). There is, though, no contradiction here. As Brande suggests, I think it is important in professional writing to keep the two sides of the writing personality together, namely the artisan and the artist. It is by being emotionally committed that one creates good art but it is by being professional that one creates good writing.

Writing the final narration

In this section I have drawn largely on Rosenthal's work since he is such an exemplary documentarist but also on Hampe and Bruzzi who provide clear advice to the would-be documentary maker.

The purpose of narration is to tell the audience things they need to understand in order to be able to follow the story (Hampe 1997:137). Hampe goes on to point out that:

> a few words of well-chosen narration can often cover what would have taken several minutes of footage to explain (Hampe 1997:137).

When there is a shortage of time, a script can cover the ground quickly as well (Hampe 1997:137). If the footage is good, then the narration can be straightforward in simple and easy to understand language. But what belongs in narration? This means that sometimes the narration has to go beyond the immediate circumstances and fill out essential details. As far as possible I have avoided this by making the structure of the programmes wide enough to include a good deal of information in both dramatic and visual form.

The writing of the narration was an important issue immediately I started the project. Usually the final narration would be written after or just before the final cut of the film, and in that sense the work presented here is a draft that can and would be adapted to suit the actual film shot. The use of narration is thought by some to have authoritarian overtones and that so-called pure verité has eliminated the need for commentary. I have difficulty with this; whilst there are certainly many problems with commentary, Bruzzi's work on the Zapruder Tapes (see chapter one) shows clearly that verité is not value-free and therefore cannot be deemed as a pure state of the depiction of reality. It is also true that whilst the use of commentary in non-fiction film does mean that values and hence political opinions, often right of centre, are being expressed, one could argue that the absence of commentary is as much a political statement of the left and left of centre, especially when juxtaposed with a selection of images that guide the thinking of the viewer.

According to Bruzzi, Rotha believed that narration was actually detrimental to the culture of the public and that there was only one legitimate use of sound, and that was in newsreel (Bruzzi 2000:40). It is worth remembering that Riefenstahl, who was undoubtedly a Nazi sympathiser herself, used no narration in the fascist propaganda film *Triumph of the Will*. Riefenstahl was, according to Steven Bach, a gifted sociopath and liar and what Bach describes as a soulless narcissist (Kershaw 2007), but my point here is that the use of narration is not always authoritarian and to suggest that it is, is somewhat naive. Riefenstahl herself, clearly from the evidence above a totally committed fascist, considered commentary to be the 'enemy of film' (Barnouw 1993:103).

It is, however, true that in some films the tone of the narration can be patronizing; bad narration is in that sense like a bad lecture, dull and uninspiring. Narration can also fail to stimulate thought and participation and instead produce dead passivity that distances the viewer from the film, and in the modern world with hand-held channel changers it can lead to channel hopping and the loss of the audience.

On the positive side, narration can quickly and easily set up the factual background to a film, complement the mood of the film and provide form and emphasis for what the viewer is about to see and experience. This means that good narration can help the viewer understand more fully what s/he is seeing on the screen. The broad function of narration is to amplify and clarify the picture that the viewer is seeing. Good narration should help establish the direction of the film and provide information that is not obvious from the visuals. Narration, if it is good, should help focus what the film is about and where it is going and can also help establish the mood of the film; it is also useful in bridging filmic transitions and turning the film in new directions.

Good narration, according to Rosenthal, should contain the five W's; who, what, where, when, and why (Rosenthal 2002:220). Narration that is written using this technique aids the viewer's understanding. When visuals are used by themselves they often make no sense, but the sensitive use of narration can lay out the essentials of a scene without necessarily describing everything. Therefore the basis of the writing for most narration is the finding and use of interesting facts and the presentation of those facts in a gripping and interesting way to the viewer. Facts are the raw material of commentary and the writer is charged with using them judiciously to write a narration that is alive and sparkling for the audience (Rosenthal 2002:221). This judicious writing is important because it keeps the audience interest and is the visual equivalent of Orwell's rules on writing (Orwell 1984:365).

As Hampe suggests, you can hardly go wrong if you write narration as if you were being fined $10 per word (1997:141). The purist position is to draw attention to the facts but present the evidence in a manner that leaves the final judgement to the viewer. As Rosenthal suggests, this is fine as a basic rule, but when writers are passionate about their subject, there is no doubt this will influence their writing (Rosenthal 2002:221). The effect of their passion is to impact on the writing and there seems little doubt that their views will be expressed in the narration. This is an appropriate position for films seeking a social change; but whilst I want my films to challenge the viewer's perceptions, a societal change to attitudes to mathematics as a subject seems highly unlikely.

Voice and style

Traditionally the style of the type of non-fiction film that I have written has been serious, but again Burke has challenged that by making his own series loose and conversational, and he often cares little for correct grammar, using colloquial expressions such as ' ain't cheap', but this technique worked well in its day (Rosenthal 2002:223). I say in its day because one has to remember that Burke was presenting in the 1970s and 80s. At that time he had a higher profile as a presenter in this country and we had yet to have the proliferation of television channels. He had also been the BBC face of science on the *Tomorrow's World* Programme and the anchor for the BBC presentation of the Apollo moon shots. His look also echoed the stereotype of what a scientist should look like, namely balding with glasses (although he read English at Oxford). I suspect that this style is now rather dated and inappropriate in the UK. However, Burke has a much higher profile in the USA and such an approach may still work in that territory. As I noted above, when I was writing the programmes I sought to try and keep a classic style of writing since until I realised that if they were ever made they would need to be presented by a 'name', and this might involve further changes. I think it is reasonable to suggest that the writing for the actor Ricky Gervais would be more informal than perhaps the style of the writing of the same subject matter for Kenneth Branagh.

Rosenthal suggests that the third person is the correct writing style for a film on the history of science because it is formal and objective (Rosenthal 2002:225). He also suggests that this writing style is distant and what he describes as 'cool' and can be perceived as authoritarian. Whilst I agree with his analysis, it seems to me that the use of characters and drama within the film alleviates this situation. This is why in Programme One, *The Dawn of Nothing*, I deliberately use the character of the MP Wolryche Whitmore to describe the character of Charles Babbage. It seemed to me that the use of an eminent contemporary character would have more emotional impact when describing the make-up of Babbage. It was important to show that Babbage as a character was an honest and dedicated man. But in reality this is my perception of him, as the writer. I had to 'give' him a personality since I needed to ensure the audience warmed to him. So I therefore deliberately foreshadowed the Whitmore speech with the Herschel comments in scene 106. This was because I thought the Whitmore speech could backfire in the sense that Whitmore could be perceived as pompous and therefore any comments made by him could be regarded as at best containing a modicum of truth but probably not. By placing the Herschel piece to camera exactly two scenes in front of the Whitmore speech I wanted to create an audience response that sees Babbage as a man of integrity, and then to tell them he set up a society at University and then married the sister of an MP, and then finally in the Whitmore speech I wanted to create the impression of a solid remarkable man. I think the sequence works well.

The above is an illustration of Rosenthal's assertion of how writing dull facts can be alleviated by allowing the audience access to real characters who tell their own story (Rosenthal 2002:225). He also suggests that by writing in the first and second person it is possible to create a sense of dialogue and conversation of commonality with the viewer. The active voice means that the writing is more energetic and more effective at communicating with and evoking an emotional response from the audience (Rosenthal 2002:226). In an earlier draft I actually had the presenter interacting with the scene in the same way that Peter Ackroyd interacts with his characters (*Peter Ackroyd's London,* BBC 2004). However, I have made the decision that this re-written style is preferable, simply because as a writer I could not be sure who would present the films.

Rosenthal further suggests that one should write with someone in mind (Rosenthal 2002: 231). To this end I wrote the films with an older relative in mind. The effect of this was to focus my mind on using appropriate language in the writing. Rosenthal then gives two basic rules for narration:

i) avoid describing what can clearly be seen and understood by most people, but

ii) amplify and explain what the picture does not show. (Rosenthal 2002: 231).

The second of these rules had a major effect on my writing *The Measurement of Uncertainty*. This was the most difficult of all of the programmes to write since the concepts inherent within mathematical probability are often perceived as counter-intuitive to real life experience and therefore difficult both to grasp and understand. For example, in the sequence on the St Petersburg paradox I talk about the subjectivity of the decision-making that an individual must engage in, before s/he places a bet. This is to do with the shift in thinking away from an expectation of equally likely outcomes to actually calculating the probability of a successful outcome. Many people find this hard to understand. If this were not true, why is it so many people believe they can win the lotto? The fact is that mathematically you have more chance of being killed by your domestic fridge than winning the lottery.

As a writer it is very difficult to find analogy that explains the magnitude of numbers in mathematics. Again sticking with the chance of winning the lottery; imagine taking a pound coin and placing it between two slices of buttered bread. Then wrap that bread in cling film and flush it down the toilet. You have more chance of seeing that pound coin again than you have of winning the lotto. This type of analogy is essential in explaining the magnitude of numbers. Rosenthal describes how Brian Winston brilliantly made cold abstract figures come to life in the narration for *Out of the Ashes*. In order to make the point about how the Nazi SS killed over one million people in Russia, he wrote:

> they shot...2 human beings per minute for every hour of every day for 500 days
>
> (Rosenthal 2002:239).

This is mastery; it illustrates the magnitude of the number in a way that is guaranteed to evoke an emotional response in the viewer, whereas dry statistics simply do not (Rosenthal 2002:238). However, given the nature of my project it would be equally wrong to have no figures. This is why in Programme One I have written about the use of Roman Numerals. Critics of the series will lament the use of the figures, however they are presented. Either the Roman numerals sequences will be perceived as intellectually weak, and therefore watering or dumbing down the mathematics, or alternatively, as boring and therefore losing the viewer. Either way as a writer I felt I would be criticised. Therefore my response to this was to make a decision that I have to demand something of the audience, to engage them in the subject matter. Hence the scenes were written to make them think a little harder rather than being totally passive. This again is part of the response that one is trying to generate in the viewer.

Atmosphere is also a huge challenge to the writer of documentary. When one is aiming to build up an extra dimension on the screen, to make the scene come to life and make the viewer's experience the fullest emotional experience possible, then, whilst it is an obvious statement, it is essential that the writing is good. One way of doing this is by careful use of what Rosenthal calls 'colour' words, adjectives that he says add 'texture' to writing. The words work in harmony with the visual; they complement each other so that when it does work the effect can be tremendous (Rosenthal 2002:234). This is something I have sought to do throughout the whole series.

One other area of voice and style is the use of the interview. It is the case that interviews can be dry, but when they are used to tell a full story, they can give us a fascinating glimpse into people's lives. The interviews where the characters gave their impressions on events were the most interesting to write. This was because they allowed me as a writer an opportunity to develop the character of both the interviewee and the subject of the conversation. All of the interviews were written as if the interviewer questions were edited out. This meant that the answers had to be full and self-explanatory. This then allowed me as a writer to develop character (Rosenthal 2002:237). It is also what makes the writing subtler and therefore more adaptable for a wider spectrum of viewers. It seems to me, as I have said earlier, that the purpose of watching a film is not just to see the participants become excited or whatever emotion they are experiencing but also for the viewer to feel it themselves.

The role of the documentary-writer, then, is to gather and organise the information and then write a programme that contains a well-organised, structured series of scenes that can be created on film or video (Hampe 1997:120). Hampe suggests that the writer in fact gifts the production team by:

- researching and planning;
- visualizing;
- organising a structure for the documentary;
- and finally by writing the words.

Informing all of these activities, however, is the commitment of the writer to the documentary form as a way of entertaining and educating without misleading. It is a demanding but also deeply satisfying challenge.

CHAPTER THREE

Some Conclusions

In the final chapter of this commentary I want to look critically at the project and evaluate the work both as a piece of creative writing and a personal journey. I will also discuss what Chris Anderson calls ' The Long Tail' (Anderson 2006) and how I see the changes in documentary as a mirror of other industrial changes.

Writing the project

The original objective of the project was to create a piece of writing that demonstrates that it is possible to write an accessible and original documentary series that conveys the beauty and universality of mathematics. On a personal level my objective was to learn a new style of writing and to be in a position to develop as a writer within that new genre.

The subject matter was based on my past experiences in education and my writing background. As Orwell says, a writer's subject matter will be determined by the age in which he lives (Orwell 1984:9-10). Certainly, the age in which we are living has an effect on the manner in which writers can develop their craft and bring it to market. It is, however, first, worth reminding ourselves of Orwell's four reasons why writers write:

- Sheer egoism;
- Aesthetic impulse;
- Historical impulse;
- Political purpose.

(Orwell 1984:10)

These reasons resonate with my own writing since there is no doubt that it is good for the ego to see the products of one's writing in the marketplace. As a non-fiction book writer I have enjoyed the experience of seeing my books in the bookshops and also receiving good reviews and emails from readers. It would be untrue to say that this is not important to any writer and in that sense I am no different. However, it made sense for me to learn how to write for a new market since as a journeyman writer it is beneficial to have more than one market where one can earn from one's writing.

Orwell's fourth point also resonated with me as a writer, writing, as he suggests, is a desire to push the world in a certain direction (Orwell 1984:10). As I have already mentioned in this commentary, I have had to question the integrity of this motive but I think it is right to both be aware of it and acknowledge it as a stage of development that every writer needs to consider, if s/he is to write ethically. I also need to comment, though, on what Orwell calls his demon. Orwell makes the point that writing is a 'horrible, exhausting, struggle, like a long bout of painful illness' (Orwell 1984:12-13). He then talks about the demon that all writers need, noting that where he wrote lifeless books and was betrayed with what he describes as purple passages and sentences without meaning, he invariably lacked a political purpose. That is how important this is for a writer who wishes to write something of substance. There has to be a purpose beyond the pleasure of writing itself, to sustain one through the battle with words.

Measuring the Project

On the whole I feel that the project is a success. I have written a series that develops the story of mathematics in a documentary framework and I have learnt to write for a new market. However, there are issues that come to the fore when one is considering writing for a new market.

For instance, it is now quite clear is that the project was far too ambitious for a novice writer. To tackle a large documentary series at a time when such series were, as I now recognise, already coming into decline as a fashion and therefore were becoming harder to market, means that the chances of commercial success were limited. As a non-fiction writer this is a state I recognise in the book market. Novices often always want to write the next great English or American novel, yet anyone who understands the market will recognise the difficulty of a new author breaking into the market. As a new writer of documentary I should have followed a similar path but simply did not have that insight into the industry. By this I mean it would have been commercially more sensible to write smaller documentaries for different audiences. This would have created a track record and meant that developing a series of this magnitude could have become a reality in the longer term. This was, then, an important lesson in the project.

Realistically, as I now look back over the period of the project, it would have been inconceivable for me to invest money in documentary production and risk it all when I can invest the same money into books. My view is that too many creative writers, and in this case I am guilty of this myself, concentrate on developing the product and then look to market it. It makes little sense to spend time producing a product and then look for a market in which to sell it. It always makes more sense to investigate the market for the writing and then create product for that market. For me this is the most important lesson from this project. To be a professional writer, it is not enough to be creative: one does have to understand the industry one is writing in and produce product for that market.

Television has changed and the documentary has changed in the ten years I have been working on this project. The societal change that we have witnessed has had profound implications for the nature and role of the television programme as a social cohesive force via the dissemination of shared values. The change, too, in the nature of society, has in turn changed both the nature of broadcasting and the role of the documentary.

The strengths of the project

As I have already stated, my original overall objectives have been reached and that is pleasing. The series as a whole does work and is a suitable project for television but probably for outlets like BBC4 or Channel 4 rather than the more mainstream BBC 1, 2 or ITV 1, 2 outlets. This is because these stations have a greater role in public service broadcasting and as such are not obliged to chase ratings. This is something of a mixed blessing since as a writer I want my work to seen by as many people as possible, but by definition the audiences watching these television channels are smaller.

The strengths of the project, as I think of them, are in Programmes One and Three, partly because these were the most original and easiest to illustrate with images. Programme One, *The Dawn of Nothing,* is a programme on the development of numbers. It is therefore extremely easy for the audience to see how it relates to their lives and to enjoy the sequential nature of the story I have written. I think the strengths of this programme lie in the fact that it is accessible intellectually because it discusses knowledge that is a commonly held currency in the population but it also has the attraction of the story that contains enough pace to maintain interest.

The programmes on numbers and codes were also easy for the audience to identify with and hopefully enjoy, because these areas of mathematics are the most accessible for an audience. *Enigma Variations*, the name of Programme Three, is essentially about algebra. However, rather than just illustrate algebra as an abstract study with symbols that for many people are meaningless, it was more appropriate to contextualise the content in a manner that intrigued and entertained the audience. The fact that this film also involves warfare and the race to break the daily codes from the Enigma machine should make it more attractive to an audience. The programme illustrates the power of algebra as a tool for data pattern analysis and the determination of sequencing. In layperson terms this means it is possible to use basic algebraic rules to determine patterns and sequences and this is what makes mathematics powerful. It is the recognition of pattern that allows prediction and the analysis of complex material.

Development as a writer

This project started in the late 1990s as a part-time research project and has been a formative experience that has run alongside the independent writing of my normal work and they have, in a sense, cross-influenced each other. The project has meant that I have had to grapple with the nuances of writing a documentary. In this way I have also discovered something about myself as a writer. I need to make it clear that at the start of this project I had a meagre set of writing experiences and have since written seven solo books, including a BBC book that became a best seller, and I have become a publisher of other people's books. However, when I look back now to 1997 I must cringe with a certain amount of embarrassment. I genuinely did think that this project would open doors for me and enable me to engage in the world of documentary as a writer. It seemed so obvious that as a writer of non-fiction, as a former teacher, as a person with broadcasting and entertainment experience, it would be a simple step to start writing documentary. I did not, though, understand the industry and this is something that I shall return to in more detail later. In the traditional model for developing television programmes it is impossible for an unknown without a track record to enter at the level I naively wished to do. However, the development of *Youtube* and *Myspace*, video-sharing platforms, has altered the balance of power within the documentary-making world.

The post-documentary future

The development of video platforms, where it is possible to share videos without huge investment of time or corporate backing, means that the effective democratisation of documentary has occurred with the development of this new technology. Previously the necessity to draw audiences to the broadcast of a mass-market programme meant that it had to be designed for as broad a range of people as possible. The arrival of cheap technology has had an empowering effect on the creativity of the public, by providing free access to broadcasting, albeit on a new platform. It is worth remembering that whilst there has been a multiplication of television channels and therefore more programming, it does not always mean that this is better programming. What it does mean is that the power to decide where, when and what one will watch on television has shifted from the producer to the consumer.

What is happening in television is an extension of a societal change that has been in operation since the 1970s. and that happened in other industries during the second half of the 20th century. Prior to the Internet, the main source of product in any sphere was local to the purchaser. Most people bought cars within perhaps 50 miles of where they lived, they listened to their own local radio station, they bought their own local paper and they rented videos from their local store. In the 1970s and early 1980s tv shows could command huge audiences; for example, in 1977 the Morecambe and Wise Christmas Show achieved an audience of twenty-eight million viewers (www.televisionheaven.co.uk 2007). Out of a country of approximately 56 million people at the time, this meant that 50% of the population were watching that show. This is the television version of Fordist production. Fordism is the social science term for producer-led consumption. The carmaker Henry Ford determined that you could have a car in ' any colour -so long, as it is black' (Ford 2007). This was a reference to the Model T Ford that was becoming a popular motorcar in the early part of the 20th century in the USA. It is a commonly held view that this was because black dried faster than any other colour, allowing Ford to make more cars in the time but this theory is not supported by fact. In reality between 1908 and 1914 and again in 1926/7 Model T's were made in different colours (Ford 2007). Under Fordism mass consumption together with mass production led to sustained economic growth and the widespread economic and material growth of living standards of the West, but the significant point is that this was producer-led supply and demand and it was to be reversed in the latter part of the 20th century.

In a post-Fordist world, however, power moved from the producer to the consumer. This phenomenon has been accompanied by a switching in economic terms from supply and demand to demand and supply (Thompson 1998:404), leading to yet further choice (Anderson 2006:169). And this applies to television where there has been an explosion of programmes, not all of them good. The viewer is now given virtually unlimited choice in what is being called 'the Long Tail' (Anderson 2006). The 'Long Tail' is an image of the infinite choice now open to consumers (Anderson 2006:180); we can see this in practice via websites like Amazon or E-Bay. It means the consumer no longer needs to purchase from the mainstream supplier. This has huge implications in the market place for the way companies do business. For example, my company now regularly sells books to people in Spain, but ten years ago it would not have been possible to link to those customers.

It seems to me that this same process is happening in television and more specifically to the television documentary. Prior to digitisation of product, and its delivery via the Internet, the amount of choice available in a particular geographical area was determined by the shelf space for the product in the local shops. This by definition comes with a cost. A vendor has to supply both the shelf and the product to sit on that shelf. This must then limit supply within that local environment. The choice of videos or DVDs that one has in a local Blockbuster store is determined by space. This in turn puts pressure on the producers of the product to create a hit, because the 'short head' of producer-led product must be successful for the company to thrive.

Digital delivery, however, means that the cost per unit is literally pence and in fact can often be fractions of a penny. Whereas previously it meant pounds or dollars per year in space rental simply to present the product to the public in a local arena, now the individual cost of unit storage is small. The individual unit sales are also small relative to the sales of a traditional blockbuster, but because of the low cost of storage and distribution, this is no longer a problem. In fact, although the individual unit sales per product may be small the overall effect on sales of the back catalogue can be huge. For example, in books, Barnes and Noble found that the bottom 1.2 million titles it sells through its US shops accounted for 1.7% of sales, yet online the same books accounted for 10% of sales. The same is true for other products; in the US PRX markets public radio programmes, the bottom 80% of its product account for 50% of its sales (Anderson 2006, 130). The same is also now true in television, Channel 4 is now offering download programmes on the internet at a charge of pence per programme; many other programmes including short documentaries are downloadable for free, at Channel 4.com.

The danger with this model from the provider's point of view is to determine where the business revenue stream comes from but social websites like *YouTube* and *MySpace* are now making a share of advertising revenue available for the contributors.

Again, the writer and broadcaster Clive James has pioneered a new style of programming which is online. He shoots a simple interview with two cameras in his library. The two cameras are important since where one camera is used, at the end of filming the interviewee, the production team then film the interviewer often repeating the questions and nodding sage like. In the trade these are termed the 'noddies' and are edited into the final production, again raising questions of how real is real (www.clivejames.com). The irony with Clive James is that his model of development has been expensive and there is no obvious revenue stream, with the guests appearing on his programmes for a take-away Chinese meal in lieu of a fee. This model shows that making documentaries and screening them online can be a new entrance mechanism to the profession and it may be the case in the near future that this entry mechanism will become the norm for new documentary makers.

In the traditional model, both the commissioning editor and the viewer come to the act of viewing a documentary with expectation, one of which is that the originator of the documentary is knowledgeable and experienced. By contrast, the new technology allows for a more open view of the documentary as something not validated by establishment values but instead by access to the web. Indeed as far as television is concerned, on January 19 2006 everything changed. This was the day, when Google, the Internet search engine company unveiled Google video (Anderson 2006:192). It was now possible, as I have noted, to make cheap videos and air them to thousands if not millions of people. Some of the videos posted on web-based platforms are getting the size of audience that many television executives only dream of - for instance, one video, on *Youtube*, has been seen by 258 155 [2] people and yet it was less than 2 minutes long (www.girlsrockmovie.com 2007). This shows the extent to which the use of web-based platforms is essential for new creative people who wish to enter and even influence the film industry. The development of video-web sharing sites means that it is now possible to create a track record, as a filmmaker, and to do so cheaply.

What we are witnessing, then, is the democratisation of media production by the creation of cheap digital production tools that allow people both to be creative and to reach an audience via the internet. This is a major challenge to the industry and to governments. Eric Pfanner reports that many

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[2] It needs to be clear that this figure is actually extremely small in terms of audience via terrestrial television.

governments are actually regarding *YouTube* as a threat. Pfanner notes that the Military Government in Thailand has blocked *YouTube* because of what it regards as the platform's 'unacceptable behaviour': *YouTube* are alleged to have allowed the broadcast of a video that denigrates the King of Thailand. In a similar manner, on April 11 2007 China quietly blocked access to *Daily Motion*, a French-based video-sharing website for what Pfanner describes as 'unexplained reasons'(Pfanner 2007).

This is also evidence of a developing crisis phase in the history of video production. Kuhn tells us that whenever orthodoxy is challenged, the developing stages that follow this challenge always include a period of what he calls 'crisis' before a new orthodoxy emerges. This crisis stage begins with the blurring of a paradigm (Kuhn1996: 84) and this is what is happening within television as a whole and short film/documentary production in particular in the form of global zoning. The search engine company Google acquired *Youtube* in 2006. Google already zones the search engine, that is regulates its content, so it could easily do the same for *Youtube*. This means that certain areas of the world, where governments are sensitive, are able to bar people in that area from accessing certain material online that the government(s) of that region regard as unacceptable. Whilst this approach is undoubtedly a form of censorship it does mean that the web-based platform as a system for film dissemination is changing its own status from emergent and therefore threatening technology to a more stable and functional technology that the establishment can adapt to and adopt within daily life.

Significantly in March 2007 the BBC reached an agreement with a video-sharing platform company to show excerpts of BBC programming on the site. This will give the web platform access to more established content and as Ashley Highfield, the BBC's director of Future and Media, put it, act as a promotional vehicle for the BBC (Webber 2007). It is what John Corner calls the post-documentary era where hybridisation occurs (Ward 2005:34), although in this case what I envisage is the hybridisation of the documentary form and the delivery of that form to the audience.

In some ways I would like to think that I have contributed to this movement by telling the story of mathematics and how it impacts on everyday life and has done so since the start of civilisation. I have also postulated about the future of society[3] as a whole and the role of mathematics within that future society. However, for me what is most important is that I have created a series of programmes that draws on the work of other writers and historians, and shows that it is possible to depict and explain what to many is an impenetrable subject, but one that shapes all of our lives, the story of mathematics.

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[3] It needs to be clear that the technicist assumptions mentioned above, whilst being technologically possible are assumptions. Simply because something is technologically possible does not mean there will be an audience for that service. In 2008 this happened in radio where Gcap Ltd (owners of Classic FM) were forced to close a number of digital radio stations. Whilst the technology made the provision on digital platforms available, there is no real demand for these services from the audience.

Programme One

The Language of the Universe

The Dawn of Nothing

One Sc 1

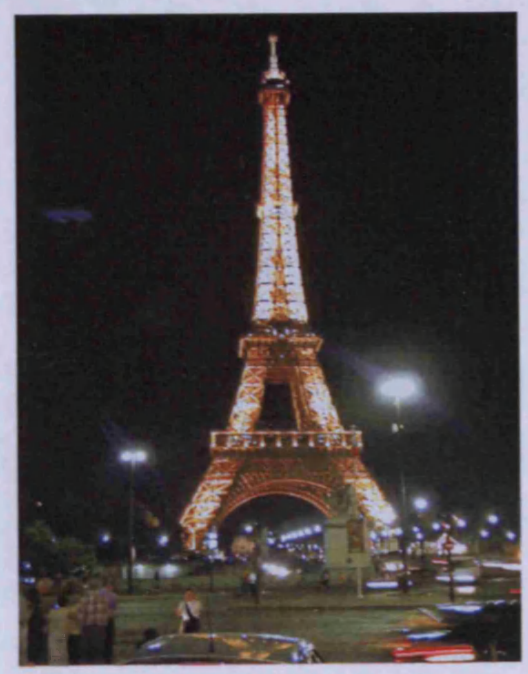
Fig 1.1 Red sky in the morning
www.artshole.co.uk
CUT TO

[Music intro

music fades
What is it that connects

this,

One Sc 2



to this?

Fig 1.2 Eiffel Tower
www.ashlintree.com
CUT TO

One Sc 3

And this,

Fig 1.3 Flowers
www.dpfwiw.com
CUT TO

One Sc 4

to this,

Fig 1.4 Frozen scene
www.aquarticles.com
CUT TO

One Sc 5

to one of the most beautiful women of her day,

Fig 1.5 Miss Milbanke
www.engphil.astate.edu
CUT TO

One Sc 6

to the most famous scandal of the late 18 th - century,

Fig 1.6 Lady Caroline Lamb and Byron
www.gothicpress.freeserve.co.uk
CUT TO

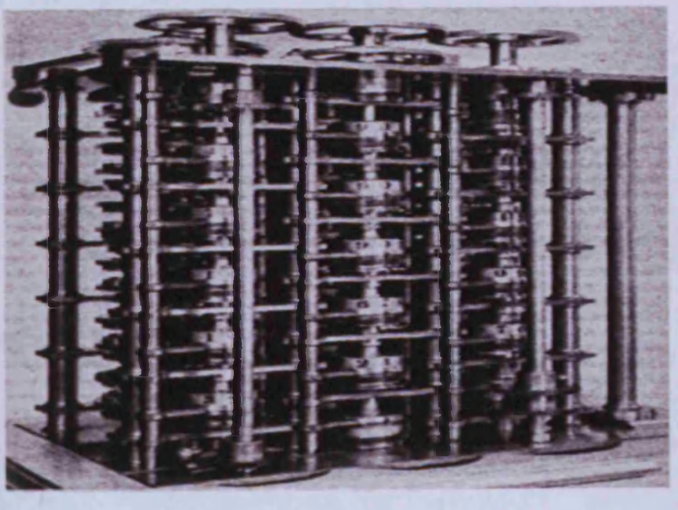
One Sc 7

to a journey across the North Sea,

Fig 1.7 Three mast full rigged sailing ship
www.schoonerman.com

CUT TO

One Sc 8



and then to a calculating device?

Fig 1.8 Babbage's Difference Engine
www-groups.dcs.st-and.ac.uk

CUT TO

One Sc 9

WE SEE AN ELDERLY MAN SITTING WITH A SET OF PLANS AND A YOUNG WOMAN IS STANDING DEFERENTIALLY NEXT TO HIM.

YOUNG WOMAN

Well Mr. Babbage, I do believe your counting machine is magnificent.

MR. BABBAGE

Miss Lovelace, you are most kind. I must say these days that I have spent working with you on this project have been a joy to me. I declare that, for a woman, you possess the most admirable of intellect.

CUT TO

One Sc 10

And why are Native Americans

Fig 1.9 Native Americans - www.nativeamericans.com

CUT TO

One Sc 11

and a zealous Scot important to our story?

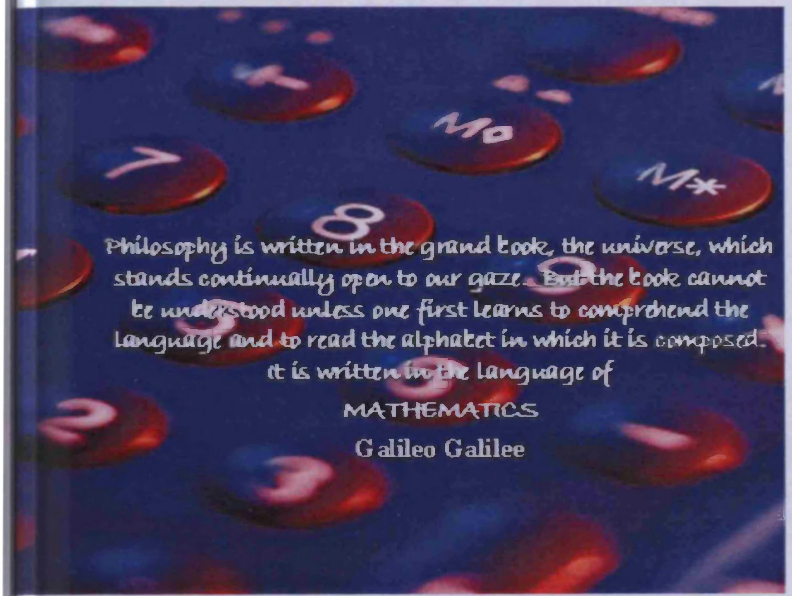
Fig 1.10 John Napier
www.katev.org
CUT TO

One Sc12

Hello, I'm Graham Lawler. The story I am about to tell you is a true story of love, betrayal, magic and intrigue. It is the story of how a language developed, a language that, when you learn to speak it, can unravel the mysteries of the universe. It is the story of mathematics.

Fig 1.11 The author
CUT TO

<u>**One Sc 13**</u>



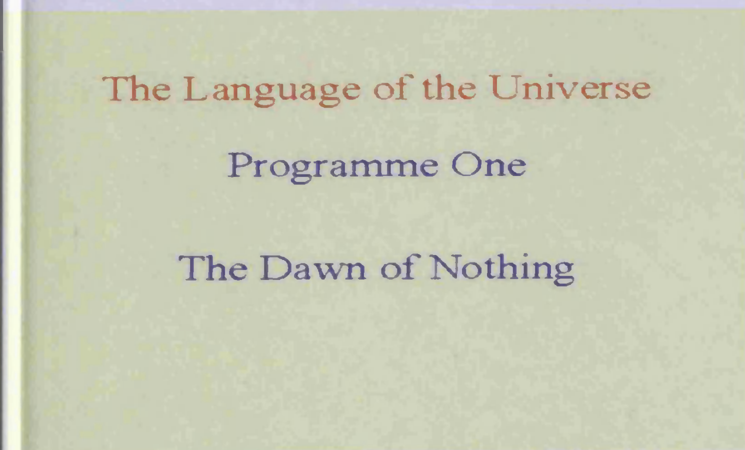
[Classical music introduction]

Fig 1.12 Galileo quotation: author-produced slide

<u>**FADE TO**</u>

<u>**One Sc 14**</u>

Titles



[Classical music]

Fig 1.13 title slide: author-produced slide

<u>**CUT TO**</u>

One Sc 15

Counting began when civilization began, and

Fig 1.14 Sky
www.nesky.org

SPIRAL FADE TO

One Sc 16

civilization began in Africa.

Fig 1.15 Map of Africa
www.bnbguidebook.

CUT TO

One Sc 17

It began in the mist of time; early man began to do something that no other animal had before or since - he began to count.

Fig 1.16 Mists of time
www.flickr.com

FADE TO

One Sc 18

It was 1959 when Mary and Louis Leakey made their historical announcement to the world; they had discovered the remains of an early man.
Scientific dating shows that it dates from 1 750 000 years earlier. This is evidence of early civilization; well, not on its own,

Fig 1.17 Mary and Louis Leakey
www.leakeyfoundation.org

CUT TO

One Sc 19

but when it is combined with the jaw found in the same area and thought to be five and a half million years old, and

Fig 1.18 Ancient human jawbone
www.bbc.co.uk

CUT TO

One Sc 20

an ancient iron ore mine found in Swaziland that is about 43 000 years old, and

Fig 1.19 Ancient Mine
www.themodernantiquarian.com

CUT TO

One Sc 21
Cave paintings

ten - thousand years old cave paintings that show that what is today the Sahara desert was once a green and verdant land, that was grazed by horses and inhabited by humans who hunted and rode chariots, then,

Fig 1.20 Cave paintings
www.tony.lownds.com

CUT TO

One Sc 22

when you start putting evidence like this together, there most certainly was a sophisticated civilization. A good example of a developed area is Lake Edward. This is where the Ishango people lived about 9000 BC and it was here that an interesting object was found. It was a bone.

Fig 1.21 Lake Edward
www.ilec.or.jp

CUT TO

One Sc 23

Fig 1.22 The Ishango bone
www.naturalsciences.be

But not just any bone. Along its length it has definite notches, which were cut for a purpose, and there is a small piece of Quartz that is fixed inside the narrow cavity of the head. Scientists have proven that it dates from somewhere between 9000 and 6500 BC.

CUT TO

One Sc 24

The notches were important; they formed a pattern and patterns are important to people in mathematics.

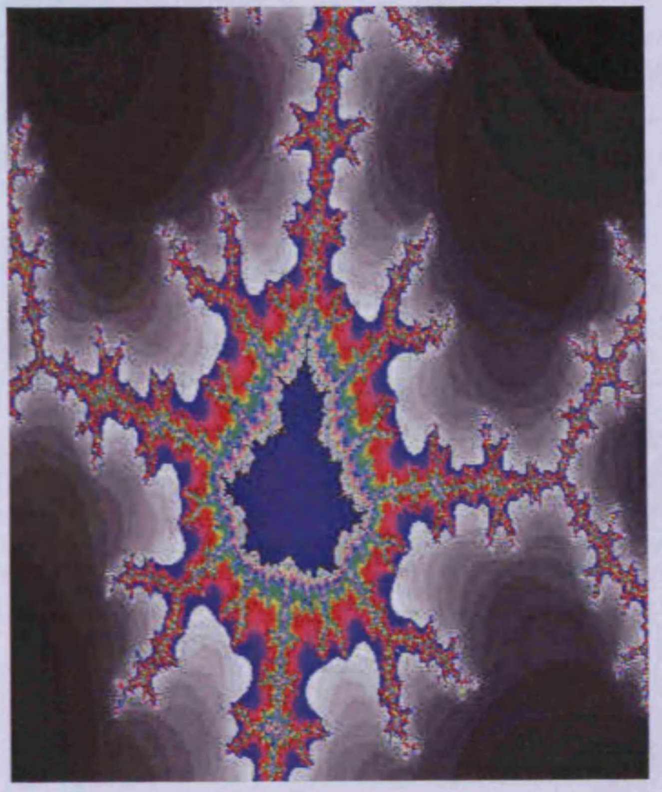
Fig 1.23 The Ishango Bone
www.tacomacc.edu
CUT TO

One Sc 25

Mathematicians like patterns because when patterns form a regular pattern, they become predictable.

Fig 1.24 Shells
www.daleyplanit.com
FADE TO

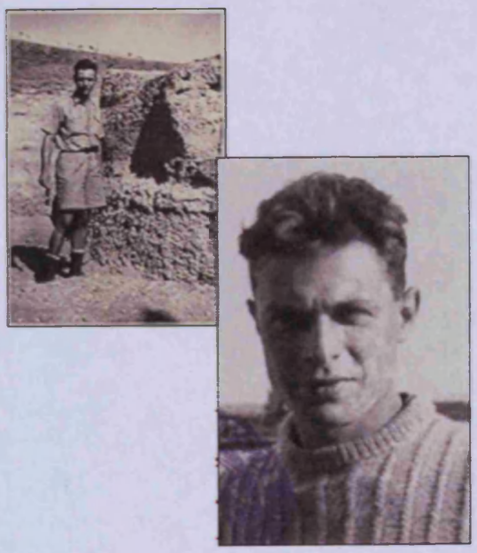
One Sc 26



In other words, they give us the power to predict what will happen. And this was why the bone was so important.

Fig 1.25 Complex fractal pattern
www.members.aol.com
CUT TO

One Sc 27



Jean de Heinzelin, the man who found the bone, suggested that it could be used as a mathematical game or even a way of presenting prime numbers. But, frankly, most people in the mathematics community were not persuaded.

Fig 1.27 Jean de Heinzelin
www.naturalsciences.be
CUT TO

One Sc 28

There is a more plausible view. This is Alexander Marshack on the right-hand side and he noticed something special, really very special.

Fig 1.27 Alexander Marshack
www.donsmaps.com
CUT TO

One Sc 29

He noticed that the patterns link with the movements of the Moon. This actually fits well with what we know about the life of the tribe at this time. We know the Ishango had to be aware of the seasons for their own well-being.

Fig 1.28 Digital moon
www.homepage.mac.com
CUT TO

One Sc 30

But for us it means something more. It is evidence of counting. People began to count because they needed to. Counting developed because it helped people to solve the problems of their daily lives. Although, in truth, we are guessing what the bone was used for, there is no doubt that it was developed because the Ishango needed to count, they needed to determine quantity, and they needed to use this knowledge to understand their environment and solve their problems.

Fig 1.29 Lake Edward
www.ilec.or.jp
CUT TO

One Sc 31

But what sort of problems? Lake Edward has tidal flows and the bone could have been a device to help the tribe leaders to decide when it was necessary to move to higher ground. This way they could avoid the flooding.

Fig 1.30 Africans
www.radiosportfm.com
CUT TO

One Sc 32

Fig 1.22 The Ishango bone
www.naturalsciences.be

This is the bone that was found by De Heinzelin in Africa. It is an artefact of man that stretches across time connecting different people in different continents, and it was in another continent that a clash would lead to a huge change in western living.

CUT TO

One Sc 33

This is Florence; it's 1259. Here two cultures are colliding and there can only be one winner. The City elders were worried and for the best of reasons.

Fig 1.31 Florence
www.bardill.net
FADE TO

One Sc 34

You see, at this time there were two ways of counting, the old way and the new way from the East. But what exactly were these ways and why were the elders so worried?

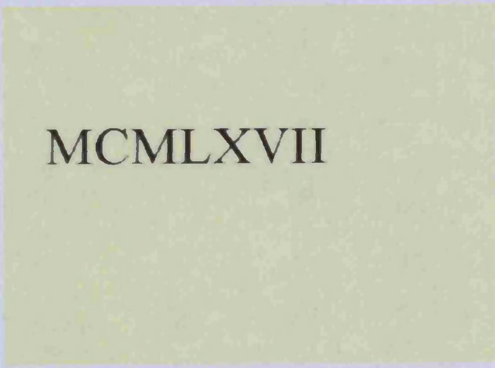
Fig 1.32 Florence
www.orcca.on.ca
SPIRAL FADE TO

One Sc 35

When the Romans ruled Europe, they established a whole culture and that included their own number system. This was so good, it is actually still in use today; you'll see Roman Numerals on the end of programmes on TV.

Fig 1.33 Roman soldier
www.web.grestone.bham.sch.uk
CUT TO

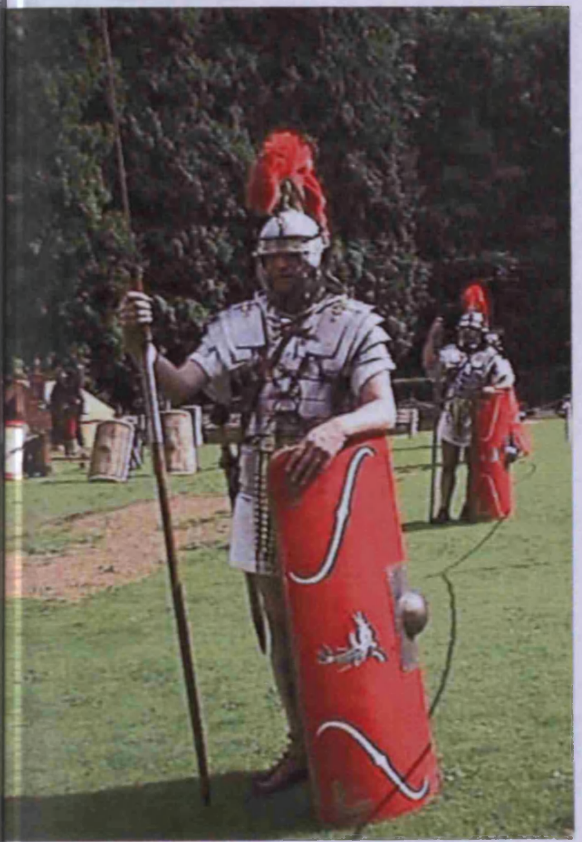
One Sc 36



But the Roman System was no match for the new symbols from the East because these numbers, Roman numerals, were actually quite difficult to deal with. For a start, letters stood for numbers.

Fig 1.34 Roman numerals
CUT TO

One Sc 37

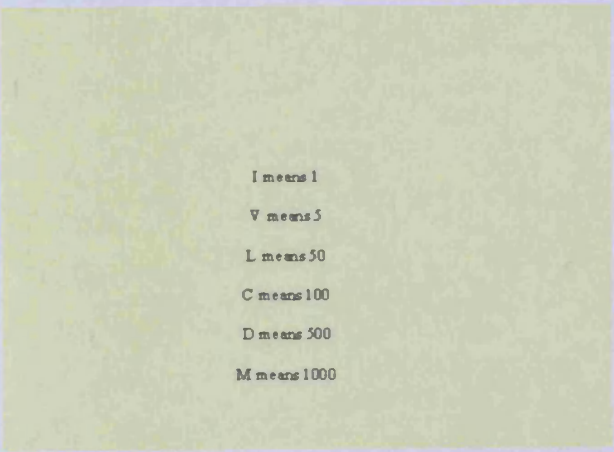


In his time you would probably have to go to university just to learn how to add up. Let's see.

Fig 1.35 Roman soldier
www.dspace.dial.pipex.com

FADE TO

One Sc 38



This looks ok.

Fig 1.36 Roman numerals2

CUT TO

One Sc 39

- Since V stood for 5, 500 becomes a $\overline{V}$

We can see how you get $\overline{V}$, but then you start to get combinations and that becomes extremely complicated.

Fig 1.37 Roman numerals 3
CUT TO

One Sc 40

1000 = M
900 = CM
50 = L
10 = X
5= V

So
1976 = MCMLXXVI

To see how complex this is, let's look at a date. Say we had to change 1976 into Roman Numerals.

Fig 1.38 Roman numerals 4
CUT TO

One Sc 41

M is 1000; CM is 900 because it means 100 before 1000

- So we have MCM that makes 1900
- Now we need to make 96
- L is 50, but what is the final answer?

Have a go yourself; try turning 1996 into Roman Numerals.

Fig 1.39 Roman numerals 5
FADE TO

One Sc 42

- MCMXCVI = 1000 + 900 + 90 + 6

So you can see how useful the numbers we now use are, particularly when you see how complex the Roman numeral system is to work.

Fig 1.40 Roman numerals 6
FADE TO

One Sc 43

Fig 1.41 Florence
www.thomashawk.com
FADE TO

In 1259 however, the numbers we use today were regarded as new symbols and these new symbols that had come from the East radically changed the way merchants and others could work. But they were opposed. Whenever new developments are introduced in daily life, they often cause fear because they are not understood or because they form a potential threat. Here, in Florence, the threat was the potential for fraud. So they banned the new symbols, possibly hoping they would go away. But how did these numbers travel to Western Europe in the first place? The answer was trade.

One Sc 44

Fig 1.42 Arab man
www.toursaudiarabia.com
FADE TO

This man was a travelling trader, one of many travelling Arab traders who came from the East to Western Europe to trade. But they were also something else, something quite special. They were, probably without realising it, an influence on life in Western Europe. They were the vehicle that created a social revolution across the whole of the western world. This is because they came from an advanced society that had created something that was extremely important and they brought this with them to Western Europe: the idea of zero.

ONE Sc 45

Fig 1.43 Whole earth jpg
www.uni-mainz.de
FADE TO

World power has not always lain in the West. Much of our developed society depends on what we have borrowed from other civilizations.

One Sc 46

Fig 1.44 Babylon
www.heartlight.org
CUT TO

A good example is Babylon. It had an advanced civilization that gave us many of the early developments in mathematics and science. The numbers we use in daily life were invented in India, but it was the Babylonians master mathematicians who really saw the power in this number system. So what was it about these new Arabic numbers that was so important?

<u>One Sc 47</u>

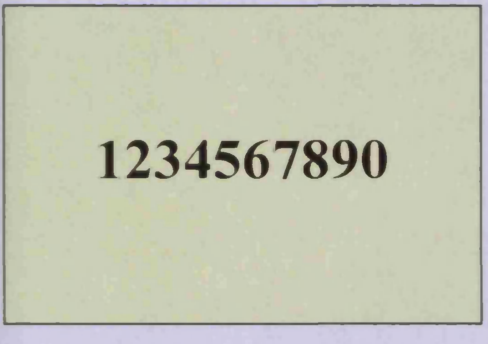


Fig 1.45 Arabic numerals 1
Author-produced slide

<u>FADE TO</u>

The beauty of these numbers is their endless combination and this is what makes them powerful. Look at this arrangement of numbers.

<u>One Sc 48</u>

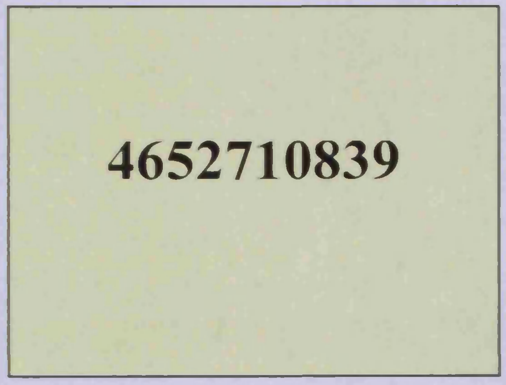
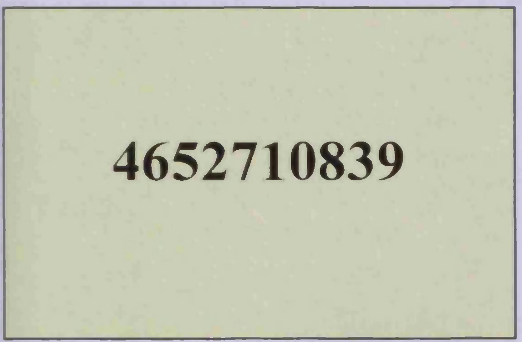


Fig 1.46 Arabic numerals 2
Author-produced slide

<u>FADE TO</u>

We can rearrange the numbers easily - for example:

<u>One Sc 49</u>

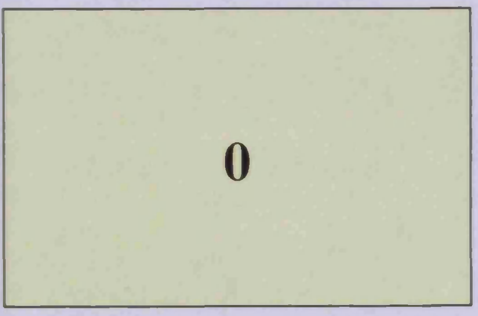


You see, the number of combinations is limitless; we don't even need to use all of the numbers. The invention of Arabic numbers had a major effect across the world. It gave ordinary people power. It freed them from Roman numerals that had shackled their ability to think. It was this freedom that changed the way we think and the way we live.

Fig 1.47 Arabic numerals 3
Author-produced slide

<u>FADE TO</u>

<u>One Sc 50</u>



This new number system had an invention that was revolutionary. This was the first time that we actually had a symbol that stood for nothing. It may sound extraordinary, but for the first time ever humankind had a way of showing nothing. And there was one more important role for zero - it was a place holder.

Fig 1.48 Arabic numerals 4
Author-produced slide
<u>FADE TO</u>

One Sc 51

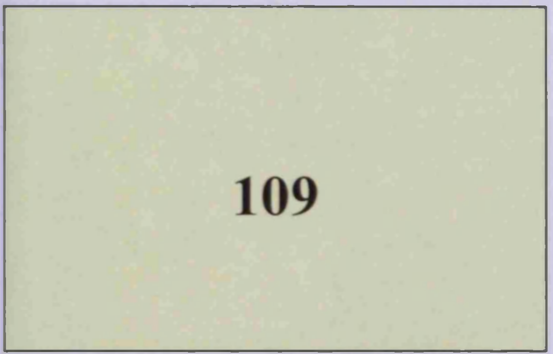


Fig 1.51 Arabic numerals 5
Author - produced slide

Here the zero is doing two jobs. It is an indication that in this number there are no tens and therefore the number reads as one hundred and nine, and in this sense it is a place holder and this is why it is so important. It is this Dawn of Nothing that clears away the mental clutter of Roman Numbers.

FADE TO

One Sc 52

Fig 1.50 Padua University
www-drecam.cea.fr

We have already seen how these new numbers caused alarm in Florence, but the Florentines were not alone.
In 1348 at Padua University, a declaration was made that all prices for studying should be written in 'plain letters not ciphers'. This was a disaster in the history of mathematics and in the development of Padua because it allowed other cities to develop further and faster. Trade became easier where Arabic numbers were adopted because of the intellectual ease with which calculations could now be performed.

FADE TO

One Sc 53

Fig 1.51 Sands of time.
www.eternelpresent.ch

But what was it that spread these new numbers around the world? Amongst other things there was a need to measure time, but with a calendar rather than with sand.

FADE TO

One Sc 54

Fig 1.53 Ancient coin
www.geldmuseum.de

There was also the growing circulation of money.

CUT TO

One Sc 55

Then there was the use of weight and measures in trade. All of these problems needed mathematics to find a solution.

Fig 1.53 Weights and measures: www.state.in.us

FADE TO

One Sc 56

The increased need to use mathematics came especially from the growth in the use of money and the growth in the amount of money came principally from trade, but what would the effect have been on society and the development of mathematics without the use of money?

Fig 1.54 Money
www.gallery.prwdot.org

FADE TO

One Sc 57

Fig 1.55 Native Americans
www.chgs.umn.edu
FADE TO

To answer this, we need to look at what happened to the native people of the American Continent.

One Sc 58

Fig 1.56 Native Americans
www.scls.lib.wi.us
FADE TO

Long before they were invaded by Europeans, there were over 500 groups of Native Americans on the continent. They had many well-developed class systems.

One Sc 59

The Maya culture had a very complex number system but these were in what is now South America.

Fig 1.57 Maya culture.
www.wildland.com

FADE TO

One Sc 60

In what are now Canada, the USA and Central America there were many widespread groups with different languages and a complex network of connections. Many of the people were nomadic; some were farmers and herded animals and their religion was spiritual.

Fig 1.58 Satellite map of North America
www.motherplanet.net

CUT TO

One Sc 61

Fig 1.59 Native Americans
www.memory.loc.gov
CUT TO

These different tribes of Native Americans were a nation at peace with themselves. This meant they had no need for numbers. They could count for their purposes but had no need to count in the way we do today. They had wise men who passed on their wisdom down the years by talking. It was an oral culture.

One Sc 62

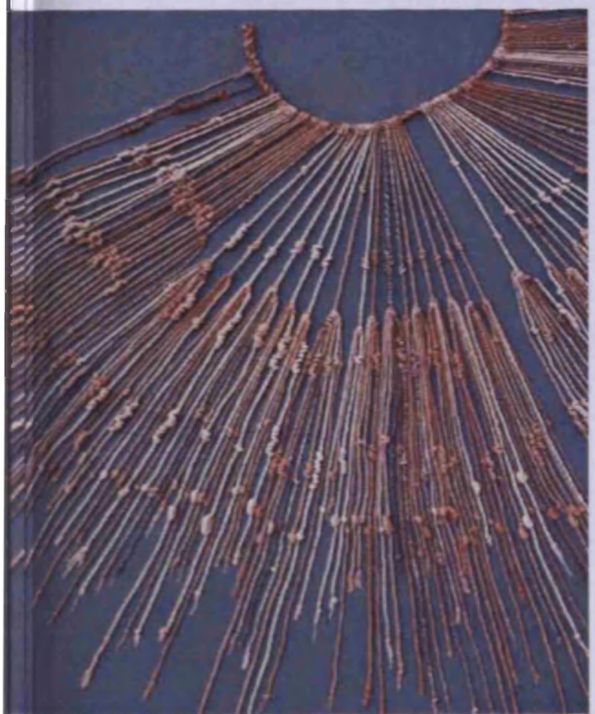


Fig 1.60 Quipu
www.instruct1.cit.cornell.edu
CUT TO

The systems that these Native Americans used fitted their society. They did not develop numbers because, quite simply, they did not need them. But it was exactly this lack of need that acted as a brake on their society. The absence of mathematics meant that they lacked the mental tools to manipulate knowledge and create new knowledge; they couldn't take something that was known and use it to develop something that previously was unknown. This was despite the fact that the Incas in South America used the Quipu (Khipu). Quipu is the Inca word for knot and it is made up of lengths of cords, usually of different colours. The Native North Americans did have a similar device called wampum, but it was the Quipu that was far more liberating and more widespread and this is what made it more influential. The more widespread a calculating device is the more people are exposed to it and the greater is the effect on human thinking. The Quipu was used as far afield as China and Ancient Greece where it was used for taxation calculation and in Africa hunters would use it to record their kills.

One Sc 63

It was even used as late as the 1830's in Hawaii as a calculating device and this is important because again it is an example of a sophisticated society where there was no written record of calculation. So why did some areas develop counting skills and others not?

Fig 1.61 Pearl Harbour Hawaii
www.celestiamotherlode.net
CUT TO

One Sc 64

One of the reasons was this stuff, metal money.

Fig 1.62 Metal money
www.fotosearch.com
CUT TO

One Sc 65

Money provides a common measurement to give value to different commodities. When you have money, you need to calculate; when you need to calculate, you need mental tools. Countries that exchanged goods for tokens that represented value, were countries that encouraged trade and trade means counting has to happen.

Fig 1.63 Coins.
www.artlebedev.ru
CUT TO

One Sc 66

The second driver that spread the use of numbers amongst the population was the need to measure time. There has been a need to measure time and its passage since civilisation first began. The measurement of time is important, because it gives us the ability to plan ahead.

Fig 1.64 Clock
www.csh.rit.edu
CUT TO

One Sc 67

Planning links society with order because it means the development of government and control of society becomes possible.

Fig 1.65 Police officer
www.hulubei.net
CUT TO

One Sc 68

But measuring time is not easy. It is simple enough to measure one day as a single revolution of the Earth on its axis, but where do we go from there? A lunar month initially looks attractive but in fact it is 29.25 days long, not exactly the easiest number for calculation purposes. The solar year is promising because it is the revolution of the Earth about the Sun, but it is 365.25 days. So measuring time has never been easy, but we owe a great deal to one man.

Fig 1.66 Lunar month
www.ejphoto.com
CUT TO

One Sc 69

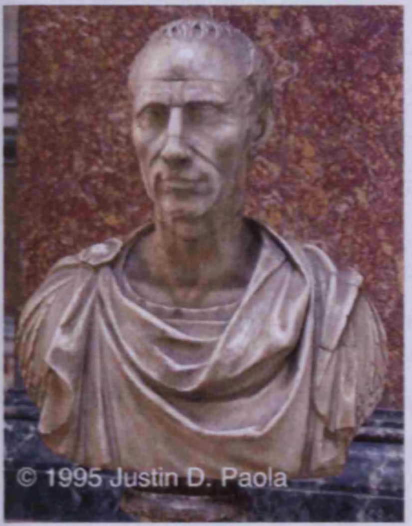


Fig 1.67 Caesar
www.thepaolas.com

It was Julius Caesar who came up with a system for time keeping because he had to. In 46 BC he drastically changed the calendar into one that we would recognise now. He had to because by 46 BC the whole calendar had become a mess.

One Sc 70

JULIUS CAESAR IS TALKING OFF CAMERA TO OUR UNSEEN REPORTER.
HE SMILES AS HE RECOLLECTS CLEOPATRA.

Ah, Egypt such a sweet vision, a vision of beauty and a temptress of the night, and an intellect that stunned me.

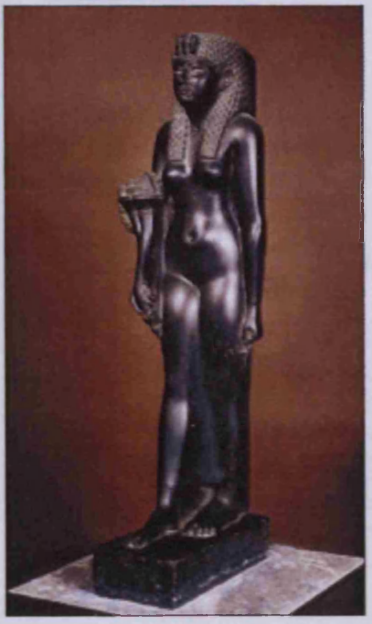
(PAUSES)

STERNLY

Cleopatra, you see, had recognised the need for an accurate time keeping device, yes she even decreed it. I could not be outdone by a mere woman so I devised a plan to …shall we say, interpret her understanding. I spoke at great length to many of her most ardent scholars and thence determined that in Egypt the year is **(PAUSE)** 365 days.

CUT TO

One Sc 71

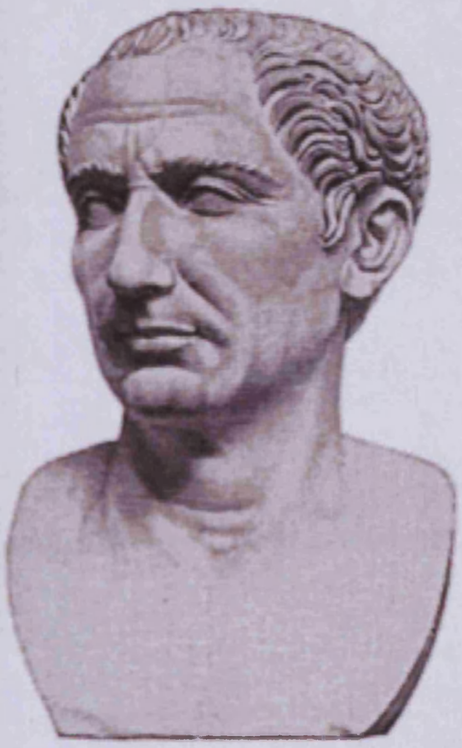


The fact that Cleopatra's scholars
had determined the length of the year so well
is testament to their abilities.

Fig 1.68 Egyptian statue of Cleopatra
www.nationmaster.com

CUT TO

One Sc 72



Once home Caesar began his reforms of the Roman calendar by closing the gap between the civil and the solar year by first of all stretching the civil year to 445 days.
He then brought in a modified Egyptian calendar and this was the mark of his genius.
Caesar decreed that every 4 years there would be an extra day, what today we know as a leap year, to make up for the fact that year is actually 365 ¼ days. .
This calendar became known as the Julian Calendar, but there was a problem that Caesar had not seen.

Fig 1.69 Julius Caesar
www.de.wikipedia.org
CUT TO

One Sc 73

Fig 1.70 365.25 days in a year
www.factbook.org

The year of 365 ¼ days is actually about 11 minutes too long. When this error is multiplied over decades it can become hours and over centuries this can become days.

One Sc 74

Fig 1.71 Vatican
www.time.com
CUT TO

Why did this matter? Well, for one reason it was to create a huge problem for the Vatican.

One Sc 75

Fig 1.72 Council of Trent
www.ignatiushistory.info
CUT TO

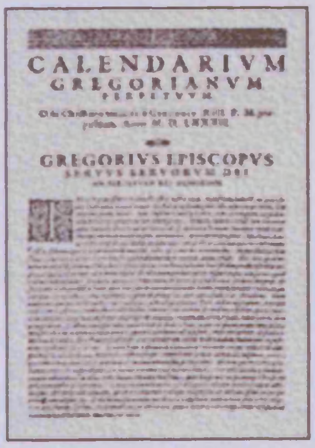
By 1545 at the Council of Trent, the vernal equinox, the date when night and day are nearly the same length, had receded from March 21 to March 11 and unless something was done, it would eventually clash with the previous Christmas. There was no option; there had to be a new calendar.

One SC 76

It was Pope Gregory XIII who in 1582 created the new calendar and we still use it today. It was called the Gregorian calendar and it had one purpose, to restore the vernal equinox to March 21 and keep it there.

Fig 1.73 Pope Gregory XIII
www.ronaldbrucemeyer.com
CUT TO

One SC 77



This led to 10 days being annulled. It meant that Oct 5 became Oct 15. This was not all. Over the next three hundred years three leap years were omitted and this gave us a calendar that was extremely close to the real length of the solar year.

Fig 1.74 Gregorian calendar
www.allourhistory.com
CUT TO

One Sc 78

Fig 1.75 Painting
www.accesshub.net
CUT TO

This caused trouble at the time, with marchers demanding that their days were returned. It was not such a stupid action as it might seem, because suddenly the day after Oct 4 1582 became October 15. These lost days were deemed by many bosses not to have been worked and therefore there was no pay due.

One SC 79

Fig 1.76 Stonehenge thought by some to be a calendar
www.studyabroad.msu.edu
FADE TO

The need for a calendar meant that numbers had to be used and this was certainly one of the reasons for the widespread use of numbers. But just as important for the spread of Arabic numbers was the need to measure.

One Sc 80

Measuring is essential in life. Before the widespread use of Arabic numbers in the form that we know them basic calculations were extremely difficult. Using Arabic numbers makes calculating easier and the ability to calculate quickly and accurately has always been the ultimate aim in mathematics.

Fig 1.77 The cast iron numbers sundial
www.get2buynow.com

CUT TO

One SC 81

By changing from Roman numerals to Arabic numerals, hours of drudgery were removed and indeed over the years mathematicians looked for various ways to remove drudgery; one such mathematician was a Scot called John Napier, who sometime before 1614 devised a simple yet powerful tool in mathematics.

Fig 1.78 John Napier
www.heritage.scotsman.com

CUT TO

One Sc 82

Napier's life's work was clear to him from an early age; it was to campaign against the Catholics in Scotland. He worked for most of his life on this but it was his hobby, mathematics that was to write his name in history.

Fig 1.79 Catholic sites
www.glasgow.world-guides.com
CUT TO

One Sc 83

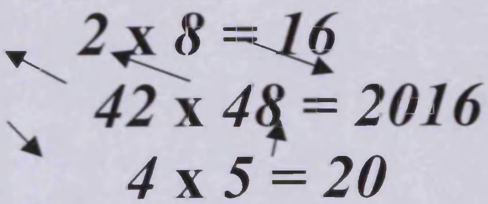


Fig 1.80 Difficulty in multiplying
Author - produced image

One of the problems of Napier's day was the need to multiply two two-digit numbers accurately. This is where he showed his genius.

CUT TO

One Sc 84

Most people see numbers like these oaks, that is, as individual numbers. But this is not right: it is an illusion. All numbers form a continuous series; the gaps between the trees have other numbers in them.

Fig 1.81 Tree - lined avenue
www.aboutcapetown.com
CUT TO

One SC 85

Fig 1.82 Avenue
www.mistersf.com
CUT TO

Now, this is more like numbers. The smaller bushes are the fractions or the parts of numbers. The trees are the whole numbers, so really the only thing special about them is that they are easier for most people to remember.

One Sc 86

Fig 1.83 Mathematics
www.francis.edu
CUT TO

This idea of a continuous series of numbers was a new understanding of number and was the basis for Napier's marvellous invention.

One SC 87

3 x 3 can be written as 3^2
so $3^2 = 9$
this means that $4^2 = 16$
and
$4^3 = 4 \times 4 \times 4$
$= 16 \times 4$
$= 64$

Fig 1.84 Powers
Author - produced slide
CUT TO

Napier, like all mathematicians, knew that there were two well-known series of numbers. These were the addition or arithmetic series, and the multiplication or geometric series.

But he was the first to realise that these numbers are connected and that the connection was true for all numbers, whether they were whole numbers or fractions, or any other type of number.
He saw a way of writing each series by using the other series.
Look at this.
In mathematics, to multiply something by itself is called squaring the number, so
3 x 3 can be written as 3^2
so $3^2 = 3 \times 3 = 9$.
This means that $4^2 = 4 \times 4 = 16$
and $4^3 = 4 \times 4 \times 4 = 16 \times 4 = 64$

One SC 88

0	**1**
1	**2**
2	**4**
3	**8**
4	**16**
5	**32**
6	**64**
7	**128**
8	**256**
9	**512**
10	**1024**

Fig 1.85 Arithmetic progression
Author - produced slide
CUT TO

Look at what this means. If we use the 2's series as an example, we can generate two kinds of progression. The one on the left is called arithmetic, as one is added to each number in turn and the one on the right is called geometric, as each number in the sequence is double its predecessor. But look at them again: there is a connection.

One Sc 89

0	1	and $2^0 = 1$
1	2	and $2^1 = 2$
2	4	and $2^2 = 4$
3	8	and $2^3 = 8$
4	16	and $2^4 = 16$
5	32	and $2^5 = 32$
6	64	and $2^6 = 64$
7	128	and $2^7 = 128$
8	256	and $2^8 = 256$
9	512	and $2^9 = 512$
10	1024	and $2^{10} = 1024$

Look at how this works. There is a clear and obvious connection between the power and the value at the end. For example, two to the power zero (2^0) is 1, so there is a link between the zero and the one.
Two to the power one (2^1) is two; this gives us a link between 1 and 2.
Two to the power two (2^2) is four, and again this gives us a link between two and four, and so it goes on down the sequence.

Fig 1.86 Powers 2 Author -produced slide

CUT TO

One SC 90

Why is this important? It was revolutionary in its day and today it is important because this fact is used in computing technology. These series form the base 2 or binary series and they are the basis of modern computer programming Napier's idea was a valuable starting point. He saw that every number could be written as the power of another number.

Fig 1.87 John Napier
www.kartozoologi.no
CUT TO

One SC 91

$2^4 = 16$

Fig 1.88 Powers 3
Author - produced slide
CUT TO

Today we call that other number the base. This means that we now have two ways of writing the same number. For a number, say 16, there is a base, say 2, and a power to which the base must be raised to make this number, in this case 4.

One SC 92

2 x 2 x 2 x 2 = 16

or

two to the power 4 (2^4)= 16

or

the logarithm of 16 to the base 4 is 2

Fig 1.89 Powers 4
CUT TO

It is the power of this number that Napier eventually named by the term we use today. It is the logarithm or, as we commonly say, log.

One SC 93

10	1
10	1
100	2

So log 100 to the base 10 is 2 and this is how we write it, but look at the numbers we started with. This is the important bit.

Fig 1.90 Logs

CUT TO

One SC 94

$$10^1 \times 10^1 = 10^{(1+1)} = 10^2$$

Look at the indices, (the small numbers set upwards). They are 1 and then 1 again, and then 2.

Remember the purpose of this calculation is to multiply 10 x 10 by adding the indices. After adding the indices we convert the answer to the sum back and this gives us the answer to the multiplication.

So by adding the indices 1 and 1, we can find the third index, 2. If we know the base, we can work it backwards and find the answer to the multiplication. Here the answer is 2 and the base is 10, so we know our final answer must be 100.

Look at it again:

$10^1 \times 10^1 = 10^{(1+1)} = 10^2 = 100$

This was the excitement in Napier's discovery.

Fig 1.91 Logs 2

CUT TO

One SC 95

Fig 1.92 John Napier
www.mat.usal.es

Napier had discovered a way of converting numbers to be multiplied, into numbers that could be added. After they were added they could be converted back. Adding is easier than multiplying, so this was a major breakthrough and news of this discovery soon spread.

CUT TO

One SC 96

Fig 1.93 Sailing ship
www.pspl.on.ca

This is also where politics takes over. Dr John Craig was the medical doctor who accompanied James VI of Scotland in 1590, to Norway to collect his bride to be, the Lady Anne. This was a way to cement relations between the two countries.

CUT TO

One Sc 97

Fig 1.94 Tycho Brahe
www.measure.igpp.ucla.edu

On the journey home the royal party visited Tycho Brahe's observatory, on the island of Hven in what was then Denmark and now is Sweden. He called it his Uraniborg, or castle of the heavens, and it was here that the Royal party were entertained by the famous astronomer, well - known as the discoverer of the "new star" in the constellation, Cassiopeia. Brahe was a real character and the King was clearly intrigued to meet the man who was the talk of Europe's elite. Tycho Brahe had amassed a mountain of astronomical information but did not know what to do with it all, until Craig told him about John Napier and logarithms. This was a revelation, a real benefit to Brahe; it was a way forward and one that would become of great use.

CUT TO

One SC 98

Fig 1.95 Johannes Kepler
www.kepler.nasa.gov

The new way of calculating, using logarithms was a key development that accelerated the work that was going on at Hven. Brahe had a new assistant, a man called Johannes Kepler, and Napier's logarithms were to have a major effect on Kepler's life. Using logarithms Kepler was able to analyse the data amassed at Hven and this would then lead to Kepler developing his three laws of planetary motion, which went on to be the foundation of Newton's work, so it was clearly a step of major importance in the history of mathematics.

But the use of logarithms would become also the bane of mathematicians' lives.

CUT TO

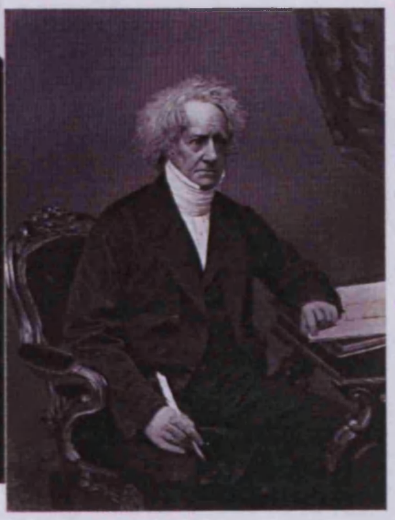
One Sc 99

Fig 1.96 Charles Babbage
www.dma.eui.upm.es

Here is where we take another jump in time to some point after 1810, where two men were working at Cambridge.
Log tables were notoriously incorrect and it was a common task to have to edit and correct them. It was whilst doing this that Charles Babbage, seen here, is said to have commented, 'tis a pity these cannot be done by steam.'

CUT TO

One Sc 100



This throw-away statement, 'tis a pity these cannot be done by steam,' was to set a course for Babbage (seen here in later years with John Herschel,) that was to occupy much of his adult life. Babbage would go on to develop a machine that could actually count, the world's first computer.

Fig 1.97
Charles Babbage
www.crowl.org

John Herschel
www.lib.utexas.edu

CUT TO

One SC 101

Fig 1.98 London: Big Ben
www.darknessandlight.co.uk

Charles Babbage was born on 17 December 1791 in London to Betsy Plumleigh Babbage and Benjamin Babbage, a banker. By all accounts he was a sickly child and this was to have a significant effect on his childhood.

CUT TO

One SC 102

Fig 1.99 Devon
www.smilodon.plus.com

Because of his ill health, Babbage was dispatched to Devon to be under the care of a clergyman who kept a school in Alphington near Exeter. The clergyman was told to prioritise his health over his learning.

CUT TO

One Sc 103

Fig 1.100 Jesus Church, Forty Hill, Enfield
www.saintmarymagdalene.org.uk

CUT TO

It was after Alphington that his education really began. He was sent to school at Forty Hill in Enfield, Middlesex, and this is where his passion for mathematics started.

One Sc 104

Fig 1.101 An 18 th - century banker
www.liverpoolmuseums.org.uk

CUT TO

School fees were clearly not a problem since Benjamin Babbage was a banker and so could afford to educate his son privately.

One SC 105

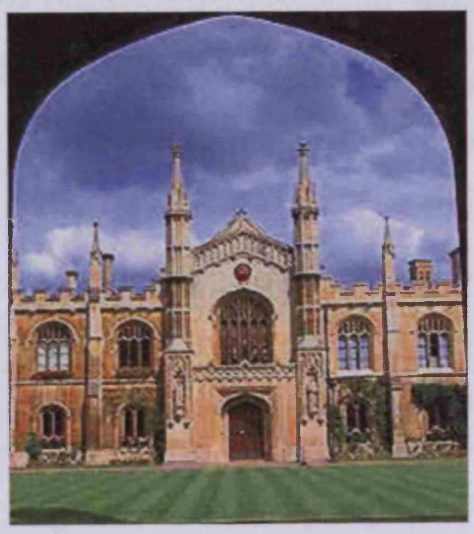
The Happy Tutor

After Forty Hill Babbage continued his education at home with an Oxford tutor who brought him up to the standard of mathematics needed for university.

Fig 1.102 The Happy Tutor.
www.smith2.sewanee.edu

CUT TO

One SC 106



He entered Cambridge in 1810.

Fig 1.103 Cambridge University
www.cambridge.world-guides.com
CUT TO

One SC 107

Fig 1.104 Charles Babbage 1791 - 1871
www.arcula.demon.co.uk

He soon became dissatisfied with the standard of teaching of mathematics at Cambridge and set about to improve things.

One Sc 108

Fig 1.105 The Cambridge campus
www.nscs.org

In 1812 Babbage established a society in the University, to translate the works of well-known mathematicians from French into English.

CUT TO

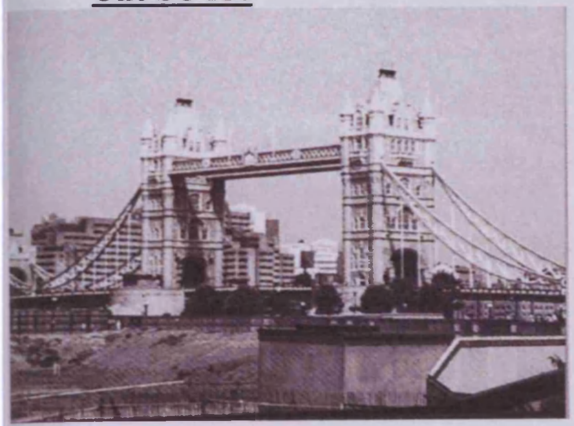
One SC 109

WE SEE JOHN HERSCHEL SITTING TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN: THE WORDS JOHN HERSCHEL ARE SHOWN.

It was a most demanding time on one's intellect. My good friend Babbage and I did resolve to mightily improve the lot of the Cambridge mathematician and we did so with great zeal. Amongst other engagements we did find the time to write a history of the branch of mathematics known as the calculus. It was, as I have said, the most demanding of times but I must say the most exhilarating. **(PAUSES FOR REFLECTION).** Men do say that the work, when one considers two undergraduates completed it, was deep in nature. This was a source of great satisfaction to me, and most assuredly so to Babbage.

CUT TO

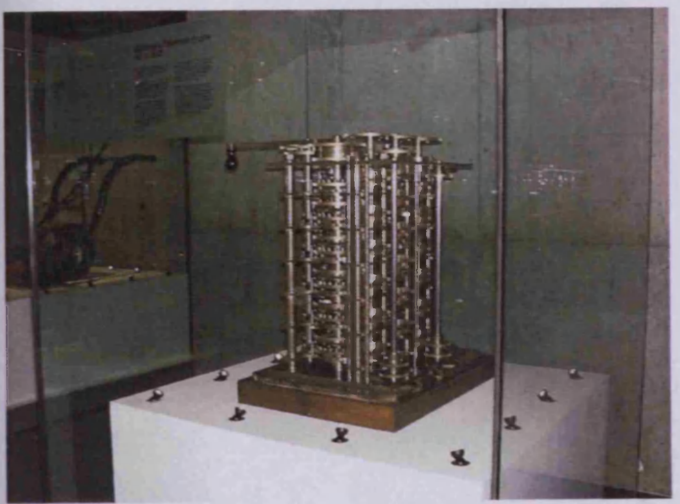
One SC 110



Babbage left Cambridge in 1815 to go and live in London. He had already married Georgiana Whitmore from a wealthy land-owning Shropshire family. Her brother was Wolryche Whitmore, the MP who had attempted many times to repeal the Corn Laws.

Fig 1.106 London bridge
www.wmich.edu

One SC 111



Babbage thought carefully about the engineering implications when he was designing his machine. He knew that he had to use the most up-to-date technology of his day and that meant precision engineering. In many ways he was fortunate that such engineering was becoming more common.

Fig 1.107 Brookfield Precision Engineering
www.boatsandoutboards.co.uk **CUT TO**

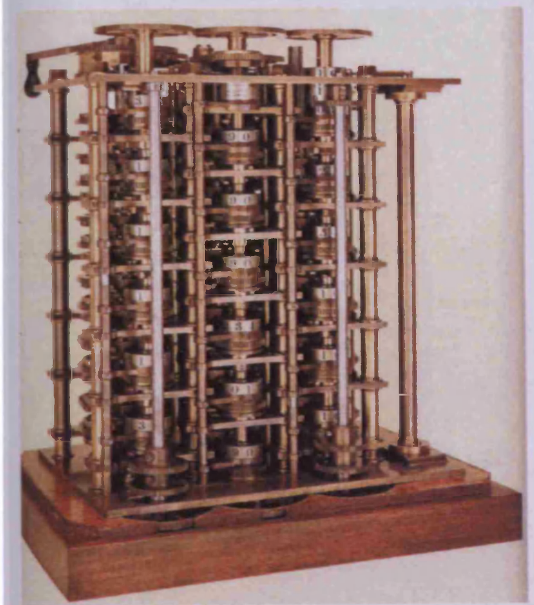
One Sc 112

WE SEE WOLRYCHE WHITMORE SITTING IN AN ARMCHAIR TALKING TO THE UNSEEN INTERVIEWER.
ON THE SCREEN IT SAYS WOLRYCHE WHITMORE MP.

A gentleman, sir, that is what sort of man he was. An absolute gentleman in the truest sense of the word. There is no finer man in England that has more integrity than my brother-in-law, Charles Babbage. Why, he is the very modicum of intellect itself. I can tell you, sir, that in the year 1816 he did join the Royal Society. Yes, by God's honour itself, the Royal Society, and yet he was dismayed at finding it was run in what can only be described as a self-congratulatory way. It was he who recognised the nature of the times in which we live. It is now some sixty years past that Adam Smith's book was published but that, sir was a pre-industrial era. Now we live in a time of industry and it was Babbage himself who recognised the role that technology is taking in the changes that this very day we are witnessing in industrial practices. Indeed, he wrote of his views in his book; er, what was it called, oh yes (PAUSE FOR EFFECT) ' On the Economy of machines and manufactures', and he did use these ideas to examine the mechanical principles that do govern and regulate the application of machinery to arts and manufactures.
And then, of course, there was his counting machine.

CUT TO

One SC 113



Babbage first began by building a calculating machine, that he called his difference engine. In mathematics difference is the word we give to indicate a subtraction. This machine used principles involving difference to calculate answers.

Fig 1.108 Charles Babbage's difference engine
www.technology.niagarac.on.ca

CUT TO

One SC 114

He then applied for a grant from the government.

Fig 1.110 Big Ben
www.buyusa.gov
CUT TO

One SC 115

But when the money came through it was not enough.

Fig 1.111 British coins
www.predecimal.com
CUT TO

One SC 116

Babbage found great difficulty in convincing the powers that be. He clearly believed they lacked vision and it was quite obvious that the nature of the mathematics was too much for many of them. Whilst they were dithering he went on to produce a second engine.

Fig 1.112 19th - century Britain
www.uk.filo.pl
CUT TO

One SC 117

WE SEE BABBAGE IN HIS WORKSHOP SEATED TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN IT SAYS CHARLES BABBAGE.

I found great difficulty in convincing those that run the country of the efficacy of my machine. They seem to lack, er, well vision. It was with the grossest lack of understanding that certain of our Members of Parliament did attend the meeting where I did explain to them the nature of the difference engine. I am left with the view that the nature of the mathematics is simply beyond them. I did resolve to use the time delay fruitfully. I should explain that the demand for a time delay was not of my doing, but was my acknowledgement of a request from the government to give them time to consider the difference engine in the fullest detail, before they could make their decision. The problem being that they took so long that I did resolve to complete a second engine. This I called my analytical engine.

One Sc 118

Fig 1.113 Charles Babbage
www.dma.eui.upm.es

The fact that Babbage developed two engines, his difference engine and his analytical engine, may have confused the politicians of the day because they did appear to have had great difficulty in understanding his requirements.

CUT TO

One SC 119

Fig 1.114 An evening soirée in progress
www.rms-gs.de

At the time it was fashionable to hold soirées. These were evening meetings where scientists would hold evening lectures and explain their work to anyone who was interested. Babbage was certainly aware of the need to create public interest and he held regular soirées to show off his work to the London establishment.

CUT TO

One SC 120

One of the attendees at Babbage's soirée was Charles Darwin; recently returned from his Beagle voyage, Darwin was keen to re-enter society and is said to have been advised that Babbage's house in Dorset Street was just the place to meet many literary people as well as many young women.

Fig 1.115 Charles Darwin
www.nmm.ac.uk

CUT TO

One SC 121

One of those young women that Darwin was so keen to meet was Ada Lovelace, a young woman in whom most of London's establishment were interested, because of one fact. Ada was the daughter of Lord Byron and the socialite Annabella Millbanke.

Fig 1.116 Ada Lovelace
www.ieee-virtual-museum.org

CUT TO

One SC 122

Fig 1.117 Annabella Milbanke
www.englishhistory.net

Annabella was an extremely confident young woman. She was described as being by no means beautiful, but she did have one particular asset that made her of interest. She was heir presumptive to substantial amounts of land that her childless uncle owned and he was, at this time, in ill health.

CUT TO

One SC 123

Fig 1.118 Lord Byron
www.2020site.org

Byron was a colourful character. He is said to have drunk claret from a real human skull plundered from old monastic grounds of his ancestral seat in Sherwood Forest.

CUT TO

One SC 124

Fig 1.117 Annabella Milbanke
www.englishhistory.net

Annabella first met Byron on the 25 March 1812 at a morning party held by Lady Caroline Lamb. Byron was one of the original celebrities. His books sold in quantities that many present-day authors can only dream about and this was at a time when the population of the country was a fraction of what it is today and the reading population even less.

CUT TO

One SC 125

Fig 1.119 Lady Caroline Lamb
www.born-today.com

LADY CAROLINE LAMB TALKING TO THE UNSEEN INTERVIEWER.

Of course, Annabelle did not agree to the union at the first, indeed there were others first. I well remember Mr William Bankes, a respectable gentleman, but he was refused. She felt he was a little (PAUSE), well, too ready to please. This was a vexation to her and one that she resolved not to accept. It was therefore with some surprise that we heard of her acceptance of Lord Byron. She did at first refuse him and wrote a long treatise on the reasons why this was a necessity, such was her nature. But a relationship did start and on January 12, 1812, they were married. We did find this difficult to believe since no one expected it to last. It was therefore hardly a surprise when it did not last.

It was I who described him as ‘mad, bad and dangerous to know’, and well described as such he was. It was on December of the same year that the child was born; they called her Ada.

CUT TO

<u>**One SC 126**</u>

The style of the time was that young women would be 'out' in society. This meant that they would spend the season in London and possible partners would be vetted. This was the accepted practice of the time and it was a rite of passage that all fashionable young people were expected to undertake.

Fig 1.120 Being 'out' in Victorian society
www.bustledress.com

<u>**CUT TO**</u>

<u>**One SC 127**</u>

WE SEE Dr BAIILEE THE FAMILY DOCTOR TALKING TO THE UNSEEN INTERVIEWER.

The marriage ended in January of the year following Ada's birth, (**SIGHS AND LOOKS SAD**), and although it took, shall we say, a little time to reach the populace, when it did, well, it was the height of scandal.
I know not the truth of some things that were imparted to me but I can tell you that two suggestions of notoriety can be laid at his, I mean Byron's door. It has been said that he is the father of a child by his sister no less. By God, yes, if it were true, and I know not, but if it were, then there is no other case than the man should be horsewhipped. Incest sir, incest.
But yet I have tales of much worse, for it is imparted to me that he was for a time at Harrow and whilst there did engage in the most bestial of acts; he did lay with other boys. By God, were this true, be sure of one thing, he would surely hang for it.

<u>**CUT TO**</u>

One SC 128

Fig 1.121 Byron and Annabella
www.englishhistory.net
www.todayinliterature.com

So here we have a marriage break-up, but no ordinary marriage break-up. This marriage was the height of celebrity but for our story it was more. Annabella has come to be seen as a cool, detached, analytical woman. Artists caricature her as a mathematician. Byron himself is caricatured as the Romantic poet but what we are seeing is that they represent a split in society between the sciences and the arts. This was the background to Ada's birth and it explains why she came to see herself as a bridge between science and arts.

CUT TO

One Sc 129

At the age of 17, on Monday 17 June 1833, Ada came to the Dorset Street home of Charles Babbage.

Fig 1.122 Dorset Street London c 1900
www.users.ox.ac.uk

CUT TO

One SC 130

CHARLES BABBAGE TALKING TO THE UNSEEN INTERVIEWER. BABBAGE IS SEATED AND WEARING VICTORIAN GENTLEMAN'S CLOTHES.
ON THE SCREEN IT SAYS ' CHARLES BABBAGE'.
Oh, what fond memories I have of that night. I declare that there were substantially more people than usual for my evenings of entertainment and enlightenment into the nature of the mathematics. One must only assume that the arrival of Miss Lovelace was an attraction in itself and indeed it was. She, of such delicate a nature, did entreat upon us with questions that were indicative of the nature of her mental enquiry. She eagerly sought out the truth. Her need to understand the nature of my engine was a delight in itself. Oh, it was such a happy meeting between us. It led to such great work together.

CUT TO

One Sc 131

ADA LOVELACE TALKING TO THE UNSEEN INTERVIEWER. SHE IS ANIMATED AS SHE TALKS, THE EXCITEMENT OF SCIENCE EVIDENT IN HER.

My visits to see Mr Babbage at his home in Dorset Street were most important to me. Whilst it did give me an opportunity to meet many people in society **(PAUSES AS SHE THINKS),** like the geologist Mr Charles Lyell and indeed the gentleman who has just been on a world trip, Mr Charles Darwin (**SHE BECOMES ANIMATED AGAIN**), my most treasured moment was the machines Mr Babbage has developed. They are the most amazing contraptions and quite startling in their lifelike manner.

CUT TO

One Sc 132

YOUNG GENT (ASIDE TO ANOTHER YOUNG GENT).
My dear Lyell, either the man is a genius or he is completely off his head

LYELL
Frankly, Darwin, I am without a care for a machine when my eyes can focus on the beauty of that young woman.

DARWIN
You may be here to witness Byron's daughter but I am here to witness the science. They say Babbage has developed a machine that can think.

BABBAGE
If you would be kind enough to follow me, I have something very special to show you.

CUT TO

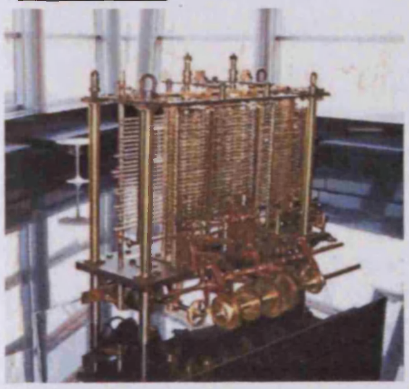
One Sc 133

WE ARE IN A SPECIALLY MODIFIED DUST - FREE ROOM. WE SEE A MACHINE THAT IS AN ASTONISHING FEAT OF ENGINEERING.

LYELL(GASPS AUDIBLY, THEN SPEAKS AS AN ASIDE TO DARWIN)
My God, Darwin, it is a most wondrous sight.
DARWIN
It is indeed.
ADA LOVELACE
Mr Babbage, you have created a most beautiful sight. It brings joy to my heart to behold this, but what does it do?
BABBAGE
Miss Lovelace, this is a difference engine.
ADA LOVELACE
A difference engine, Mr Babbage?
BABBAGE
Yes, Miss Lovelace, I have called it a difference engine.
ADA LOVELACE
Oh, how marvellous, but what does it do?
BABBAGE
Miss Lovelace, this is a device that can calculate numbers.
DARWIN
I say, Babbage, that is a mighty challenge.
BABBAGE
And one, sir that I shall demonstrate.

CUT TO

One Sc 134



And that is exactly what he did. Just imagine the effect on those people present. For the first time in human history a machine was calculating numbers and getting the right answer, every time. It certainly impressed Ada Lovelace.

Fig 1.123 Babbage's machine
www-03.ibm.com **CUT TO**

One Sc 135

ADA LOVELACE SITTING TALKING TO THE UNSEEN INTERVIEWER.
I was captivated. Mr Babbage had created a most beautiful machine, but I am most pleased to say that I did understand the nature of its workings. This is most satisfying to me. It enables me to work with Mr Babbage and I have endeavoured to create a set of instructions to aid those who wish to work the machine in the future.

CUT TO

One SC 136

Ada Lovelace was determined to improve her own knowledge and set out to meet as many informed people as she could and in1834 Ada met the acclaimed Mary Somerville, a noted mathematician and scientist of her time.

Fig 1.124 Mary Somerville 1780 -1872
www.lib.hku.hk

CUT TO

One SC 137

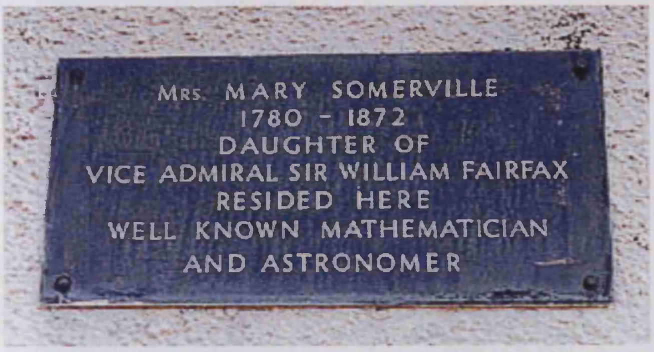


Fig 1.125 Burntisland, Fife – Plaque commemorating the life of Mary Somerville
www.burntisland.net

Mary Somerville was the daughter of William George Fairfax and his second wife Margaret Charters. She was born in the church manse in Jedburgh, the home of her mother's sister Martha Charters and Martha's husband Thomas Somerville. Mary's father was a naval officer, later Vice-Admiral Sir William George Fairfax, who was at sea at the time of her birth. Mary's mother had visited London, from their home in Fife, where her husband embarked on a long sea voyage. Margaret Fairfax broke her journey north at Jedburgh where Mary was born.

CUT TO

One Sc 138

MARY SOMERVILLE TALKING TO THE UNSEEN INTERVIEWER.
I had received a modicum of recognition at this time from my work but although I have intelligence and perseverance, it is not in my view given to my sex to have genius.

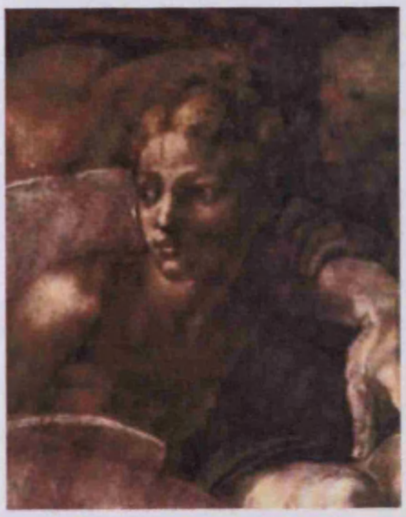
CUT TO

One SC 139

Looking back now, we can see that Mary Somerville's assessment of her own abilities was wrong. She most certainly did have that personality element we call genius, even if she herself did not recognise it. She had translated the French mathematician Laplace's work into English, and even he had said his books were unreadable. This, in English, became a five-volume work called ' The Mechanism of the Heavens', a complex survey of celestial mechanics. In the translation she wrote what was called a preliminary discussion, which was an introduction to the mathematics that the reader needed to know about. She also found errors in the tables on the motion of Uranus.

Fig 1.126 Mary Somerville 1780 - 1872
www.lib.utexas.edu

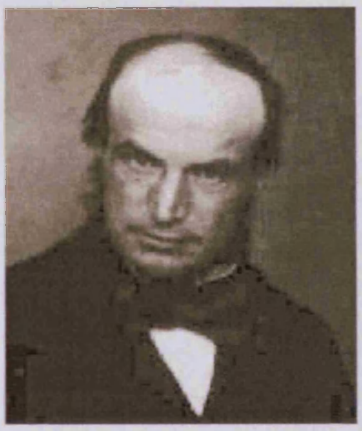
CUT TO
One Sc 140



By the time Ada met Mary Somerville, Mary had received a modicum of recognition for her work but she certainly underestimated her own abilities. She was a product of her time where it was widely and wrongly believed that women could not possess genius.

Fig 1.127 Painting entitled- ***The genius of women***
www.secondspring.co.uk
CUT TO

One Sc 141



It was the fact that Mary Somerville had determined anomalies in the orbit of Uranus that made the astronomer John Adams question why such anomalies occur. He investigated the possible existence of another planet farther out than Uranus and this is how Neptune was discovered.

Fig 1.128 John Couch Adams
www.starchild.gsfc.nasa.gov

CUT TO

One Sc 142

JOHN ADAMS THE ASTRONOMER TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN IT SAYS 'JOHN ADAMS ENGLISH ASTRONOMER'.

It was the fact that Mary Somerville had determined anomalies in the orbit of Uranus that made me question why such anomalies occur. I did resolve to investigate the possible existence of another planet farther out than Uranus and thus Neptune was discovered.

CUT TO

One SC 143

WE SEE MARY SOMERVILLE TALKING TO THE UNSEEN INTERVIEWER.
I was born Mary Fairfax in 1780 and I had an upbringing that discouraged the thoughts about mathematics.
(PAUSES AND SMILES IN RECOLLECTION OF HER CHILDHOOD, AS SHE THEN SPEAKS THERE IS A GIGGLE IN HER VOICE)
My elementary education in the mathematics came from the women's journals. They were mainly puzzles and such; I then borrowed books from my brother to determine my full understanding of the algebra. Papa thought this most unseemly for a young lady and when I was caught reading them in my bedchamber, he immediately withdrew my use of a candle. Given that I had the need to be both a good daughter and the desire to understand and determine the nature of the mathematics, I studied the puzzles in the journals during the day but not with the purpose Papa discerned. (SHE LAUGHS AT THE MEMORY). In fact, my purpose during the day was to memorise the true nature of the puzzles and as I lay in my bedchamber at night, I received great contentment in the solution of these puzzles. It was most vexing for Papa but I did not disobey him at any time.

CUT TO

One Sc 144

ADA LOVELACE TALKING TO THE UNSEEN INTERVIEWER.
It was a most agreeable meeting from the first. I was a little in awe of her but I determined that we would and indeed we did become firm friends. And of how I did gain much pleasure from those meetings. Mary was such a genius in explaining the mathematics to me but it was my own inheritance that prevented me accessing some of these ideas.

CUT TO

One Sc 145

Fig 1.129 Ada Lovelace, aged about 19
www.plus.maths.org

Was Ada Lovelace a good mathematician? Well, probably not. The evidence is that she struggled with certain aspects of mathematics but that does not diminish her role in the history of mathematics. She saw herself as a unifying force, one that would bring together the marked separation of the arts and the sciences but that was not to be.

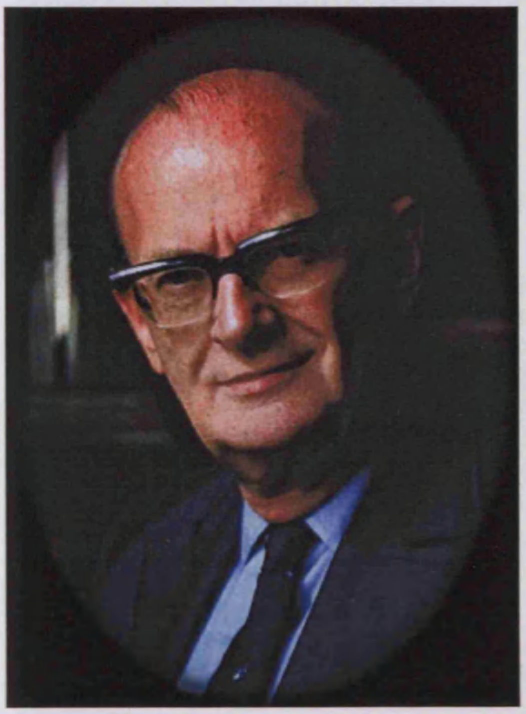
One Sc 146

Fig 1.130 Ada Lovelace,
www.ieee-virtual-museum.org

CUT TO

Throughout the 19^{th} and indeed the 20^{th} century the arts and sciences grew further apart, not least because of the way mathematics came to dominate our lives through computers.

One SC 147



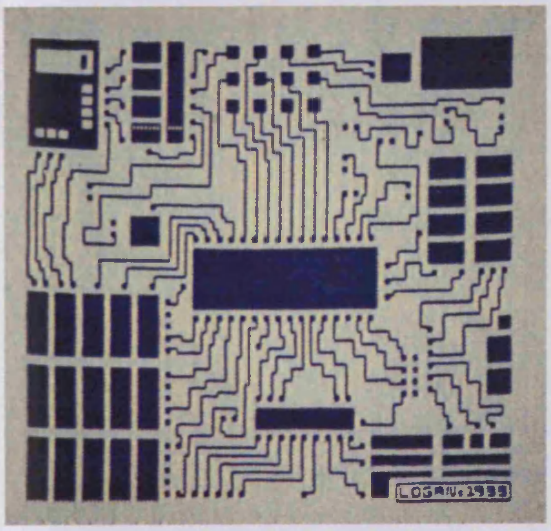
Your home computer probably has more power in it, than the computers that sent the rockets to the moon in the 1960's.

But, what of the future for science and mathematics?

Arthur C Clarke once said that the future will be exciting and he is probably right.

Fig 1.131 Sir Arthur C Clarke
www.timskoch.com
CUT TO

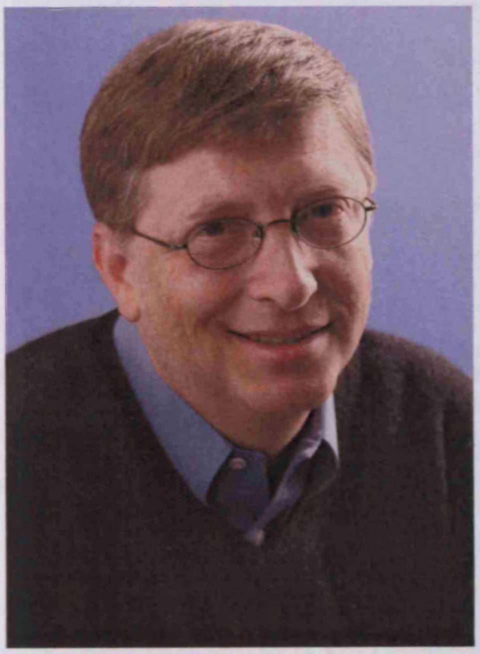
One SC 148



In fact we now live in the digital age, where signals are digitised and are represented by 0's and 1's.

Fig 1.132 Digital Interface by W Logan Fry
www.nd.edu **CUT TO**

One SC 149

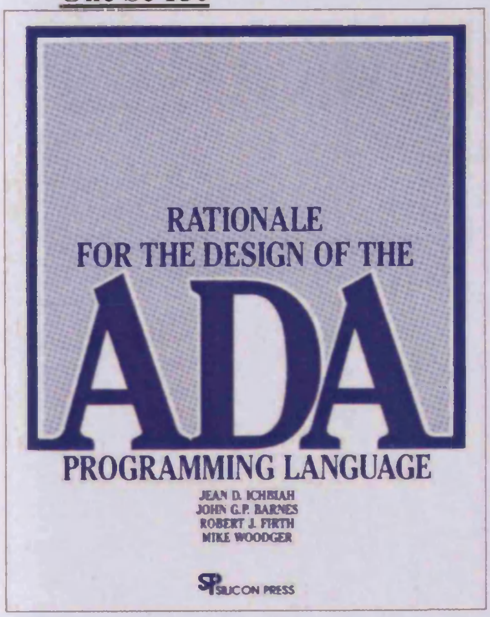


In the 1980's we started a new revolution, what some people are calling the information revolution. When the history of this period is written, it will show that this period in our lifetime is as important as the industrial revolution. Charles Babbage and Ada Lovelace could not have imagined the world in which we now live. The use of digitised signals means that we now have faster communication than ever before; we send more and more data with television signals and modern life is now almost totally dependent on these computers.

Fig 1.133 Bill Gates, courtesy of the Microsoft Corporation
www.microsoft.com

CUT TO

One Sc 150



But there is one legacy at which Ada herself would have blushed. Tragically she died at the early age of 36 but she is remembered today. To honour her place as the first computer programmer, the US forces have named one of their pieces of software after her.

Fig 1.134 Ada Programming Language
www.silicon-press.com

FADE TO THEME MUSIC AND CREDITS

Programme Two

The Language of the Universe

On Earth as it is in Heaven

TWO SC 1

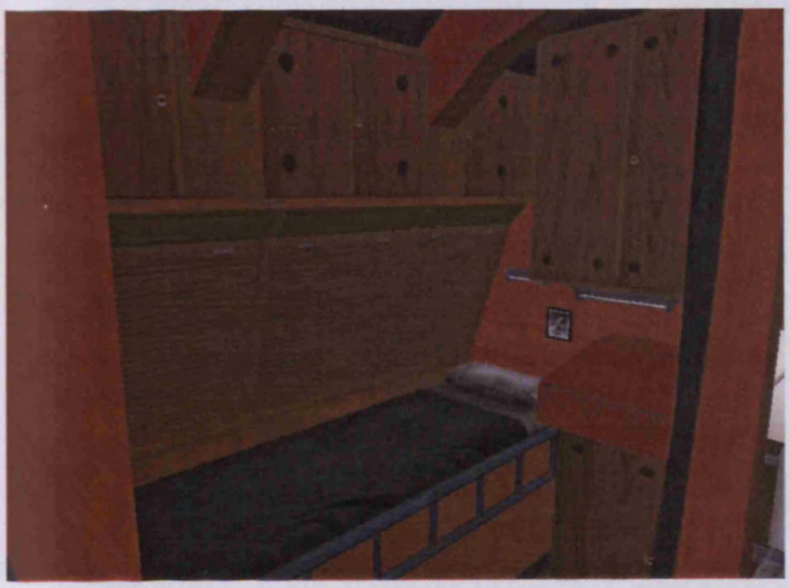
WE SEE A FOGGY DAY AND WE ARE ON BOARD A SHIP. THE WEATHER IS LOOKING BAD, AND WE HEAR DRAMATIC CLASSICAL MUSIC.

In this programme we trace how the need to measure longitude is connected to a major trial that led to a celebrity spending the rest of his life under house arrest which in turn led to Isaac Newton's work on gravity and Einstein's work on relativity, but it all began on board a ship.

Fig 2.1 Ship in trouble.
www.sea-room.com

CUT TO

TWO SC2



[INSIDE THE CAPTAIN'S CABIN CREAKING NOISES]

Fig 2.2 Captain's cabin.
www.mp-labs.com

CUT TO

TWO SC3
WE SEE THE DATE ON THE LOG AS OCT 22ND 1707.

Fig 2.3 Captain's Log.
http://www.spminiatures.com/nflogbook.jpg

CUT TO

TWO SC 4
WE SEE A CLOSE -UP OF THE CAPTAIN'S FACE; HE IS CLEARLY A WORRIED MAN; OFF SCREEN KNOCK ON CABIN DOOR.

Fig 2.4 Sir Clowdisley-Shovell.
www.submerged.co.uk

CUT TO

<u>TWO SC 5</u>

SAME ACTOR AS IN LAST SCENE

CAPTAIN
' Yes'

<u>CUT TO</u>

<u>TWO SC 6</u>
DOOR OPENS AND AN OFFICER ENTERS, PUSHING A SAILOR IN FRONT OF HIM

<u>CUT TO</u>

<u>TWO SC 7</u>

WIDE SHOT SHOWING THREE MEN IN THE CABIN

CAPTAIN
'What is the meaning of this?'

OFFICER
'Admiral, this man has asked to see you.'

OFFICER TO SAILOR
' This is Admiral Sir Clowdisley Shovell, so mind you speak well, man.'

<u>CUT TO</u>

<u>TWO SC 8</u>
CAPTAIN'S POV (Point of View)
WE SEE THE SAILOR
CLEARLY AFRAID
<u>**CUT TO**</u>

<u>**TWO SC 9**</u>

JOHNSON'S POV

Fig 2.4 Sir Clowdisley-Shovell.
www.submerged.co.uk

CAPTAIN
'Mr Johnson, what does this man want?'

JOHNSON
'Speak, man.'

SAILOR
' Sir, I knows I shouldn't have but I 'ave been keeping me own charts like and I reckons we are off course.'

ADMIRAL SIR CLOWDISLEY SHOVELL (SMILING)
'Mr Johnson, as a mark of my thanks, could you take this man on deck.'

<u>**CUT TO**</u>

<u>**TWO SC 10**</u>

WE SEE SAILOR
SMILING

<u>**CUT TO**</u>

<u>**TWO SC 11**</u>
CLOWDISLEY SHOVELL'S
FACE BECOMES SEVERE

'And hang him.'

<u>**CUT TO**</u>

TWO SC 12

Fig 2.5 Bryher, Isles of Scilly.
www.breakswithtradition.com
CUT TO

Whether this story of the hanging is true, we'll never know. It may be the creation of a 19 th-century Salonian poet called Robert Maybe.

TWO SC 13

Fig 2.6 Cezanne, Paul: The Hanged Man's House.
www.artchive.com
CUT TO

What is true is that later that night there was severe trouble as the three ships, led by Shovell, foundered.

TWO SC 14
IT IS NOW DARK, AND WE SEE THE SHIP BEGIN FOUNDERING ON THE ROCKS. WE HEAR SCREECHING BREAKING TIMBERS.

Fig 2.7 Ship on rocks.
www.marinesalvagepi.com
CUT TO

TWO SC15
WE SEE A SCARED FIRST OFFICER (JOHNSON) AND A SCARED ADMIRAL

[Music]

Fig 2.8 Two English Ships Wrecked.
www.nmm.ac.uk
CUT TO

<u>TWO SC 16</u>
WE SEE A LONG SHOT OF THE BEACH; THE ADMIRAL IS LYING ON THE BEACH WITH SAILORS LYING AROUND DEAD OR DYING.

What is also true is that the locals raided the wreck and salvaged what they could, including personal possessions.

Fig 2.9 Grave of Rear Admiral Shovell
www.submerged.co.uk/ association.php
<u>CUT TO</u>

<u>TWO SC 17</u>
WE HEAR 'DANGEROUS' MUSIC, WE SEE A GYPSY - LIKE WOMAN APPROACH THE ADMIRAL, BEND DOWN AND PICK UP HIS HAND.

Fig 2.10 Gypsy woman.
www.makeup-fx.com
<u>CUT TO</u>

TWO SC 18
WE HEAR THE SAME 'DANGEROUS' MUSIC; WE SEE A CLOSE - UP OF HIS HAND, SHOWING A BEAUTIFUL EMERALD RING.

Fig 2.11 Ring.
www.bromes.com
CUT TO

TWO SC 19
WE HEAR THE SAME 'DANGEROUS' MUSIC; WE SEE A CLOSE - UP OF THE WOMAN'S FACE: IT IS CRAGGY AND WEATHER WORN, AND THERE IS A SNEER OF GREED.

Fig 2.10 Gypsy Woman.
www.makeup-fx.com
CUT TO

The ships were well off course. It was a foggy night, on Oct 22 1707 when the Isles of Scilly, off the South-West Coast of England, became a graveyard for 2000 souls.

TWO SC 20
WE HEAR THE SAME 'DANGEROUS' MUSIC.
WE SEE HER REMOVE A KNIFE FROM SOMEWHERE IN HER DIRTY CLOTHING.
CUT TO

TWO SC 21
WE HEAR THE SAME 'DANGEROUS' MUSIC. WE SEE THE BLADE MOVING TOWARDS THE FINGER AND SHE IS CLEARLY INTENT ON CUTTING OFF THE FINGER.
CUT TO

TWO SC 22

It was a major disaster and all caused by one thing, their inability to work out where they were as they travelled the world's oceans.

Fig 2.12 The world's oceans from the South Pole.
www.search.com
CUT TO

TWO SC 23

WE SEE A CLOSE - UP OF TIMBER STREWN ROCKS AND PERSONAL BELONGINGS LITTER THE SCENE. THE WAVES ARE CRASHING ONTO THE ROCKS.

Fig 2.13 Salvage.
www.badarai.asn.au

The first to strike was the flagship, The Association. Within minutes she went down. Next came the Eagle and then the Romney, which was unable to respond fast enough.

CUT TO

TWO SC 24
WE SEE THE DEAD BODY OF SIR CLOWDISLEY SHOVELL LYING DEAD

So what had gone wrong?

The problem was at the time that there was no reliable way of working out where you were on the earth's oceans.

Fig 2.4 Sir Clowdisley-Shovell.
www.submerged.co.uk
CUT TO

TWO SC 25

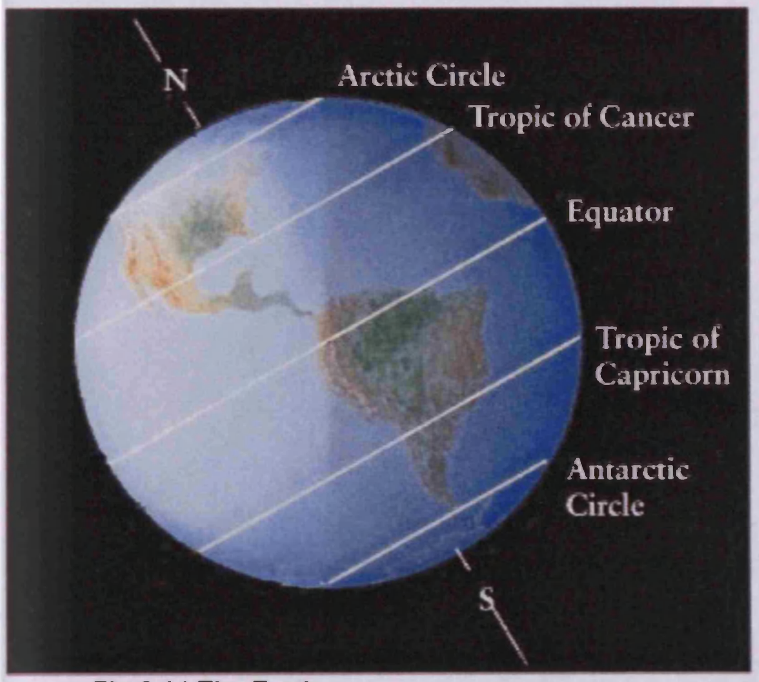


Fig 2.14 The Earth.
www.astro.washington.edu
CUT TO

Here you can see the imaginary lines of the Equator, the Tropic of Cancer and the Tropic of Capricorn. These are lines that are part of a series of circles called concentric circles that encircle the Earth. These are called Lines of Latitude.
But the ones we want to look are the ones that loop from the North to the South Pole; these are called lines of Longitude.

TWO SC 26
WE SEE A SPEEDED UP VIRTUAL REALITY OF THE SUN, THE MOON AND THE PLANETS PASSING OVER THE EQUATOR AND WE HEAR HOLST, THE PLANETS.

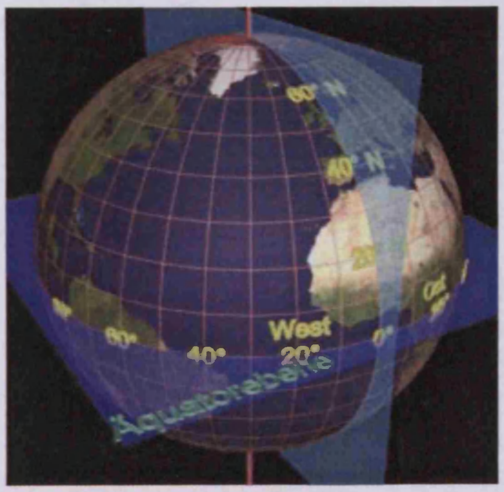


Fig 2.15 Earth.
www.kowoma.de
CUT TO

Longitude is different; here the rings went from pole-to-pole.
A ship's longitude was a way of tracking its course across the oceans, but the only way they could work out where they were was by using a technique called dead reckoning.

Two Sc 27

WE SEE A SHIP AT SEA WITH AN OFFICER THROWING A LOG OVER THE SIDE, ATTACHED TO A LONG ROPE.

Fig 2.16 Ship at sea.
www.holyhead.com

CUT TO

The log acts as a temporary sign. Here they are launching a log overboard and will time how long it takes them to travel forward. This was a common system but was a crude speedometer. The details were then noted in the ship's log with the direction of travel, usually taken from the stars or a compass and the length of time they had been on the course they were on. The system was often then used as a means of establishing longitude and plotting the future course, but was often wrong.

TWO SC 28

But why was it such a problem?

Fig 2.17 **Sailing Ships.**
www.nevture.info

CUT TO

TWO SC 29

The answer lies in this, but to understand why, we need to go back to 1609.

Fig 2.18 Incense burner.
www.innergifts.com
CUT TO

TWO SC 30
WE SEE A SMALL, RED HEADED MAN IN A CHURCH LOOKING THOUGHFULLY AS THE PRIEST CONDUCTS THE RITUAL.WE HEAR CLASSICAL MUSIC GENTLY IN THE BACKGROUND.

Ssshhh, he's counting.

Fig 2.19 Galileo.
www.jrscience.wcp.muohio.edu
CUT TO

TWO SC 31

This is the Cathedral in Pisa and he is Galileo, the legendary Italian mathematician. He was a remarkable man and was said to have rather more children than a bachelor should have.

Fig 2.20 Pisa Cathedral.
www.faculty.valencia.cc.fl.us
CUT TO

TWO SC 32

In fact, Galileo was watching the pendulum of the incense burner and he was using his own pulse to time the swing of the pendulum. This was how he noticed that the swing of the pendulum was regular and he then set out to find out why this was so. It was this line of thinking that led him eventually to suggest the idea of the pendulum clock in 1637. More importantly in the history of mathematics, Galileo was starting to develop ideas by using a quantitative approach.

Fig 2.16 Incense burner.
www innergifts.com
CUT TO

TWO SC 33

Fig 2.21 Pisa Cathedral view of apse.
www.si.umich.edu
CUT TO

It was here at Pisa that Galileo was taught what was called Aristotelian physics, but he soon began to question the basis of what he was being taught.

TWO SC 34
WE SEE AN IMAGE OF ARISTOTLE

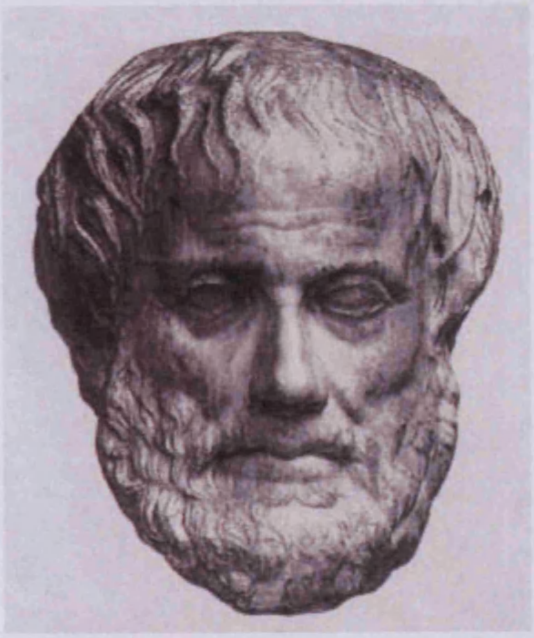


Fig 2.22 Aristotle.
www.faculty.washington.edu
CUT TO

At this time Aristotelian physics was still the predominant way to explain the behaviour of bodies like planets near the Earth or objects actually on the Earth.

TWO SC 35

Fig 2.23 Canonball.
www.civilwardealers.com

It was believed that a heavy body like a cannonball was one in which the element of the Earth predominated. So it therefore sought its natural place at the centre of the Earth.

CUT TO

TWO SC 36

Fig 2.24 Galileo.
www.eo.ucar.edu

Where Aristotle's approach had been verbal and qualitative, Galileo did the opposite.

CUT TO

TWO SC 37

He was one of the first Early European mathematicians to use quantitative methods and mathematical reasoning to explain natural phenomena and it is this that marks his genius.

Fig 2.25 A 16th-century lithograph printing mathematics.
www.wally.rit.edu
CUT TO

TWO SC 38
WE SEE FEATHERS FALLING LIKE SNOWDROPS ALL AROUND THE SHOT

Aristotle argued that heavier bodies fall faster than light ones in the same medium, but Galileo came to believe that the difference in their speed depended on the density of their bodies. The mathematics can become complex here, but it is enough to say that Galileo's method showed that it was not the weight of the objects that mattered but rather the ratio of their mass and volume. This is the density of the object and cannonballs are denser than feathers.

Fig 2.26 Falling feathers.
www.fotosearch.com
CUT TO

TWO SC 39

Fig 2.27 Galileo.
www.rakemag.com

It was this rigorous approach in Galileo's work that meant he was different and that is what marked him out as special. He looked to the skies and applied his knowledge of mathematics and science to solve problems on earth; it really was a case of on Earth as it is in Heaven.

CUT TO

TWO SC 40

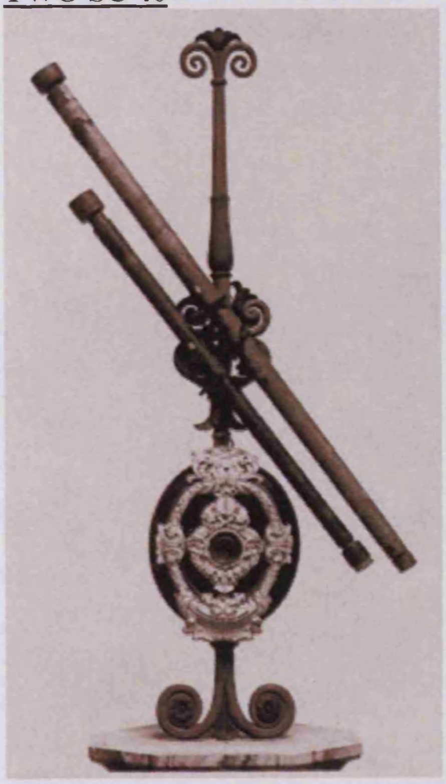


Fig 2.28 Galileo's telescope.
www.esa.int/images/ Galileo_telescope_L.jpg

For example, Galileo worked with telescopes and was one of the first to look up at the moon and say what he saw.

CUT TO

TWO SC 41

Fig 2.29 The Moon.
www.pa.msu.edu/.../ moon/moon-20day-2845.jpg

It was by looking at the moon and determining the cycles of the moon that early scientists were able to work out ways of locating a ship's position on the oceans.

CUT TO

TWO SC 42

Fig 2.30 The Moon in colour.
www.nssdc.gsfc.nasa.gov

In 1514, a German Astronomer called Werner suggested using the Moon's motion as a location finder, but the problem was that the movement of the stars was not well known at this time.

CUT TO

TWO SC 43

So Galileo kept working and he found what he thought would prove to be the clockwork of the heavens.

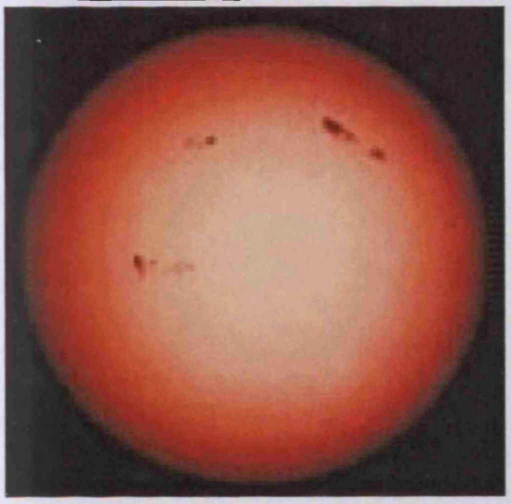
Fig 2.31 Galileo.
www.york.ac.uk
CUT TO

TWO SC 44

He saw the mountains on the moon.

Fig 2.32 Galileo's actual drawings.
web.hao.ucar.edu
CUT TO

TWO SC 45



He saw sunspots.

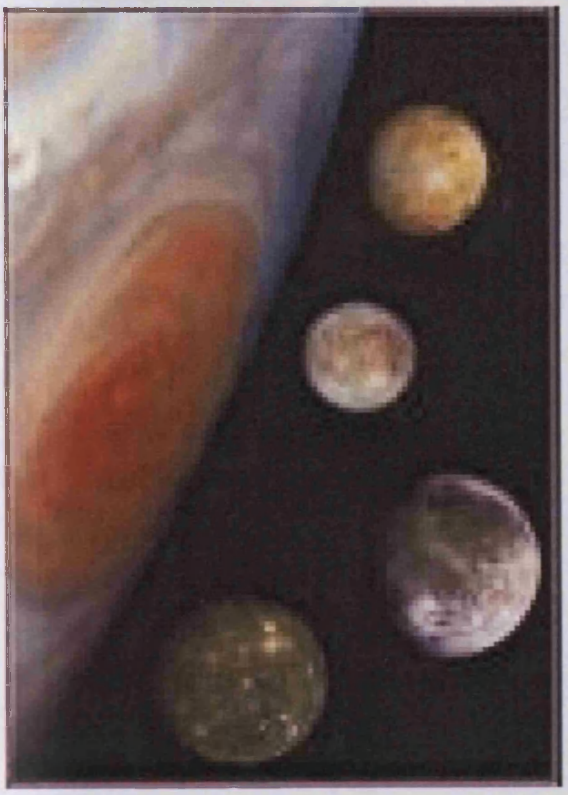
Fig 2.33 Sun showing sun spots.
www.planety.astro.cz
CUT TO

TWO SC 46

He saw Saturn's rings.

Fig 2.34 Saturn's rings.
www.universetoday.com
CUT TO

TWO SC 47

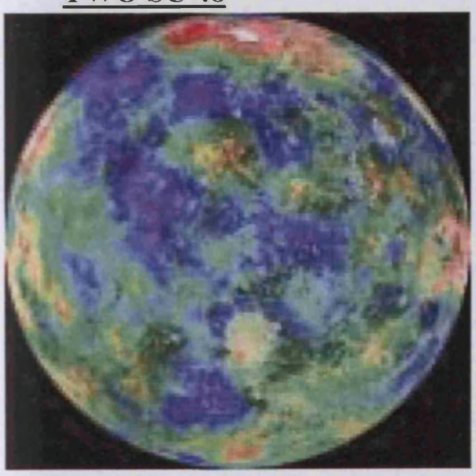


He also discovered four satellites orbiting Jupiter.

Fig 2.35 Satellites around Jupiter.
www.solarsystem.nasa.gov

CUT TO

TWO SC 48



He knew all about the Longitude problem and using his knowledge of Jupiter, he found a solution.

Fig 2.36 Image: 0 Degrees East Longitude.
www.earthandspace.info
CUT TO

TWO SC 49

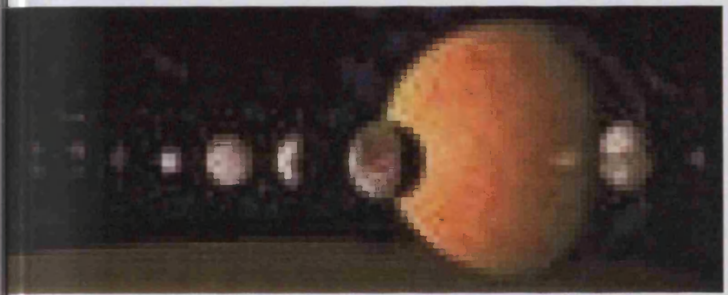


Fig 2.37 Jupiter's moons.
www.americandigest.org

CUT TO

Galileo looked to the stars to find the answers to problems here on earth. That was possible because mathematics is a universal language.
To start with Galileo noticed that each of the eclipses of Jupiter occurred around 1000 times per year and was predictable. Such predictability was extremely useful.

TWO SC 50

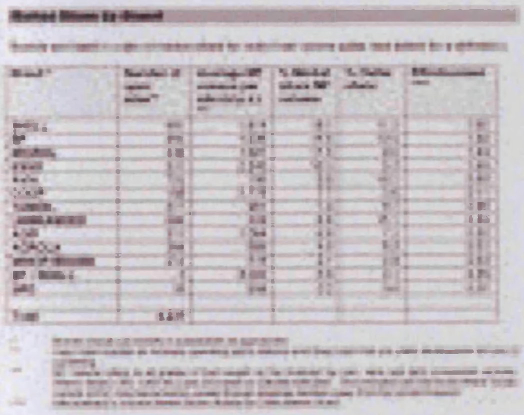


Fig 2.38 Tables of predictions.
www.npnweb.com
CUT TO

He created tables to predict each satellite's expected disappearances and reappearances over the next few months. Galileo saw that this was a possible solution to the Longitude problem and set about writing to the King of Spain.

TWO SC 51

Fig 2.39 **King Phillip III.**
www.eurotravelling.net

Twenty years earlier, Spain had become the first country to offer a prize for the solution to the longitude problem with King Phillip III offering a large prize. The trouble was there were so many crank solutions on offer. For example, one solution had been to make a cut in a dog's skin on land and on a similar dog at sea. The timing of the healing was somehow supposed to tell the sailors the longitude. Philip became bored by it all and in fact it is doubtful if the King ever saw Galileo's ideas. But what is true is that almost ten years after Galileo's death, his tables were being used on land to refine contemporary maps.

CUT TO

TWO SC 52

Fig 2.40 Painting called 'The Canvas of God'.
www.agapewebpromotion.com

Galileo, although a brilliant mind, was politically naïve and miscalculated the effect of his work. The mindset at this time was quite straightforward. The stars were the place of God and were therefore heavenly.

CUT TO

TWO SC 53

The Church had decreed that all of the planets were perfect spheres but Galileo had looked at the moon and found it was anything but a perfect sphere.

Fig 2.41 Surface of the moon shot from the Spacecraft Apollo 10.
www.nasa.gov
CUT TO

TWO SC 54

This is what started the trouble. Galileo had contradicted the Church's doctrine that all heavenly bodies were perfect spheres; Galileo said they were not. Although all he did was look up and say what he saw, it was the way he did it that caused the challenge to the Church, and the news was electric. Sir Henry Wooten, the British Ambassador, sent an urgent message back to London; the Court had to know the potential of the upheaval.

Fig 2.42 Horse rider.
www.digitaltoast.co.uk

WE HEAR AN ACTOR AS SIR HENRY WOOTEN IN THE VOICE OVER.

'The mathematical professor at Padua hath said that the moon is not spherical but endued with many prominences.'

PRESENTER V/O
CUT TO

To understand this story we need to go back to 1543.

TWO Sc 55

Fig 2.43 Copernicus.
www.academic.brooklyn.cuny.edu
CUT TO

In 1543, Copernicus had published a book called 'The Revolution of Heavenly Orbs'. In this book, he had hinted that, contrary to Church doctrine, the Earth might not be at the centre of the Universe. This statement in itself, to 21st-century ears seems innocent enough, but it was a direct challenge to the orthodoxy of the Church and it was far too dangerous for Copernicus to say it outright.

TWO SC 56

Fig 2.44 Monk at work.
www.ccat.sas.upenn.edu
CUT TO

But Galileo did say it. He said it first in 1597 when he wrote to Kepler and said "Like you, I accepted the Copernican position several years ago and discovered from thence the causes of many natural effects which are doubtless inexplicable by the current theories."
Galileo showed that the sun was at the centre of the universe and he seems to have expected everyone to accept what he said, but he was wrong, very wrong. His opponents started to collect evidence against him. They were going to make him pay, however long it took, and it took until 1633.

TWO SC 57

Fig 2.45 Sign.
www.codinghorror.com
CUT TO

The Catholic Church had found itself under intense pressure from the Protestant Reformation. The political situation was in chaos. The Protestant Reformation had achieved a number of successes, which had led to the Roman Catholic Church mounting a Counter Reformation.
Galileo's pronouncement was, in fact, very badly timed; at least for him it was. In 1624 Pope Urban VIII had met with Galileo and told him that he could discuss Copernican theory as long as it was treated as a hypothesis. By 1633 Galileo was in serious trouble.

TWO SC 58

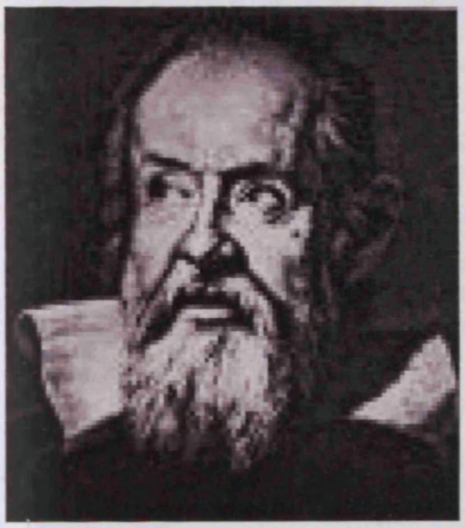


Fig 2.46 Galileo.
www.bemyastrologer.com
CUT TO

For the past twenty or so years, Galileo had moved along a road that would eventually undermine him. The truth was that there was a huge division between him and those in authority. They believed that faith should pre-dominate whilst he believed that the dominant factor should be scientific truth. There was an impasse, there was simply no common ground, so he had to be silenced.

TWO SC 59

In 1633 he was put on trial, but as with any political trial, there is an undercurrent and a history.

Fig 2.47 Trial of Galileo Galilei.
www.law.umkc.edu

CUT TO

TWO SC 60

Here in the famous Corridors of the Vatican lies Codex 1181. This is the document that listed the proceedings against Galileo. The trial began in 1633 but the documentation began just over twenty years earlier, in 1611.

Fig 2.48 Corridors of the Vatican.
www.atwtravel.net

CUT TO

TWO SC 61

Fig 2.49 Italy.
www.cnn.com
CUT TO

Reports on Galileo had been filed in 1613, 1614, and again in 1615. Galileo had himself become so alarmed at what was happening that he travelled to Rome in 1624 to see the Pope, and it was here that Pope Urban VIII gave him permission to treat the Copernican view as a hypothesis.

TWO SC 62

Fig 2.50 Cardinals.
www.dw-world.de
CUT TO

He tried to persuade the Cardinals that he knew not to outlaw the Copernican World System.

TWO SC 63

Fig 2.51 Galileo's Problems with the Church.
www.2020site.org
CUT TO

But he was already too late. The Church had already decreed that certain propositions were forbidden. These included saying that the Sun was at the centre of the universe and that the Earth was not at the centre of the universe. Remember, this was 17 years before his trial.

TWO SC 64

Fig 2.52 The Universe of Galileo.
www.muse.tau.ac.il

CUT TO

Following the Pope's permission, in 1630 Galileo wrote a book called 'The Dialogue of the Great World Systems.' He presented his point through characters. In the book, there were three characters, one who put forward objections to the Copernican theory and the other two who answered them.

TWO SC 65

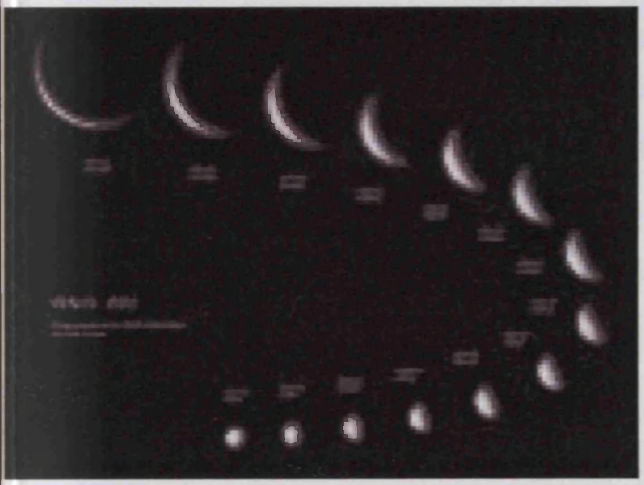


Fig 2.53 Copernican model.
www.vt-2004.org

CUT TO

We need to be aware that the Copernican view was not self - evident, especially at this time to those untrained in Science. How does the Earth spin around the Sun once a year and on its own axis once a day, without the whole of humanity spinning off? How can things be dropped and land on a spinning Earth? These were objections that Galileo dealt with on behalf of the long dead Copernicus.
Galileo defied the establishment for a dead man, Copernicus' theory, because he believed it to be true.

TWO SC 66

Fig 2.54 Galileo & The Telescope.
www.galileo.rice.edu
CUT TO

What Galileo did was to give us a sense that there are laws that are uniform throughout the universe. By working through experiments here on Earth we can gain knowledge about the stars. By looking upwards he ended the classical belief that the heavens are perfect and unchanging and that change only occurs on the Earth.

TWO SC 67

Fig 2.55 Cover of Galileo's book 'Dialogue on the Great World Systems'.
www.landskrona.astronomy.museum
CUT TO

When Galileo's book, 'Dialogue on the Great World Systems' was finished, there were powerful forces raging against it. Galileo found it really difficult to get it licensed but it was published in 1632 in Florence and was an immediate success.

TWO SC 68

Fig 2.56 Pope Urban VIII 1632.
www.69.20.65.141
CUT TO

Now the trouble began. The Pope had taken great exception to the book. Rome ordered all presses be stopped, all books bought back, but it was too late. So what was it in the book that caused so much anger? Well, it seems to have been that one of the characters in the book was a simpleton called Simplicius and it may be that the Pope felt that he was Simplicius and was insulted by what he read.

TWO SC 69

Fig 2.57 Galileo forced to recant.
www.galileosastronomos.tripod.com
CUT TO

So on 12 April 1633, an old, tired, ill man was put on trial. He was not tortured but he was certainly shown the instruments of torture and he was forced to recant.

TWO SC 70

Why is this trial important to our story? It is important because it acted as a brake on scientific and intellectual developments in Europe. Catholic scientists fell silent all across Europe. Notable people like Descartes

Fig 2.58 Descartes
.www.philosophy.umd.edu

CUT TO

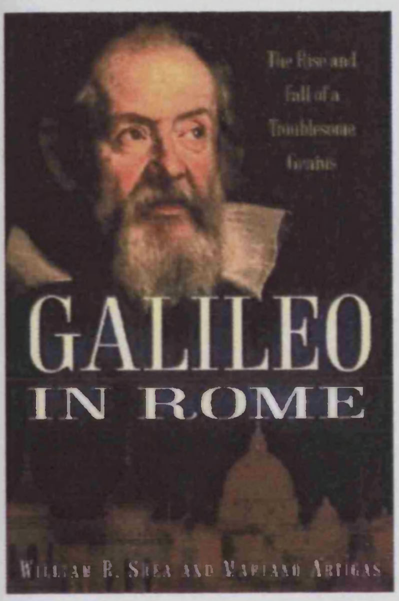
TWO SC 71

stopped publishing and moved to Sweden. It marked the end of the development of the scientific and mathematical tradition in the Mediterranean and its movement Northwards.

Fig 2.59 Sweden.
www.europa.eu.int

CUT TO

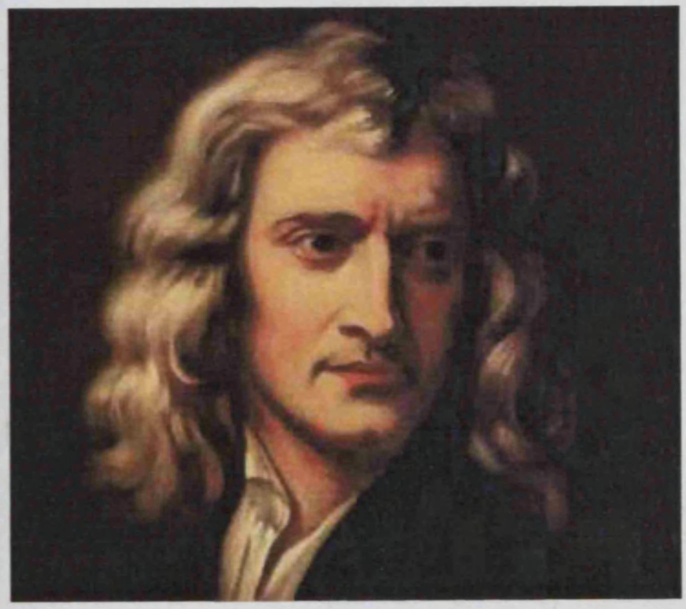
TWO SC 72



Galileo spent the rest of his life as a prisoner in his own home. He died in 1642.

Fig 2.60 Galileo on book cover.
www.voicewin.com
CUT TO

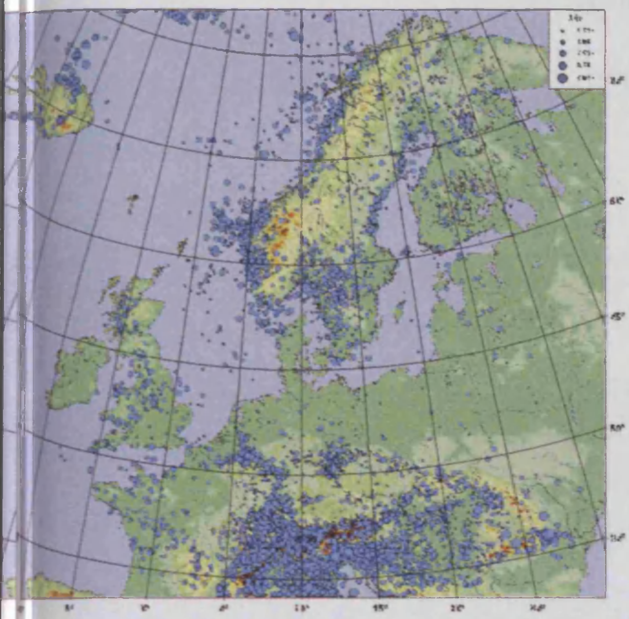
TWO SC 73



In England, on Christmas Day of the same year, a baby boy was born who would grow up to be a remarkable man. His name was Isaac Newton.

Fig 2.61 Sir Isaac Newton.
www.biografiasyvidas.com
CUT TO

TWO SC 74



By 1650, the world in which Newton was growing up had changed. The centre of the so-called civilized world had moved from Italy to Northern Europe.

Fig 2.62 Central Northern Europe.
www.seismo.ethz.ch
CUT TO

TWO SC 75

One of the main reasons for this was the discovery of America.

Fig 2.63 Melaka - replica trading ship.
www.members.virtualtourist.com
CUT TO

TWO SC 76

These were different times, with a different political outlook and they were driven by the Protestant seafaring Nations of the North, principally the Netherlands

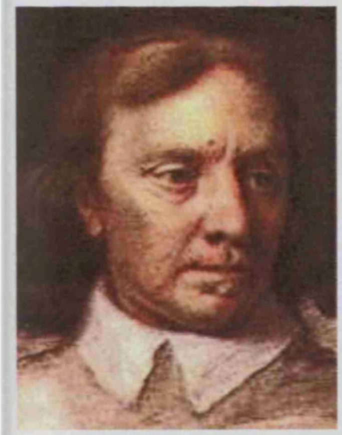
Fig 2.64 Zaanse Schans Dutch windmill.
www.exploitz.com
CUT TO

Two Sc 77

and England, now in 1650 under the rule of Oliver Cromwell.

Fig 2.65 White Cliffs of Dover.
www.dover-web.co.uk
CUT TO

TWO SC 78



> **WE SEE OLIVER CROMWELL SITTING TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN WE SEE THE WORDS OLIVER CROMWELL.**
>
> 'I did resolve to create a Godly Nation. Let us not forget, we had put the King to death and defeated the Royalists England, at this time was a republic.'

Fig 2.66 Oliver Cromwell 1643-1658
www.newgenevacenter.org
CUT TO

TWO SC 79

Cromwell had died in 1658 and his son Richard Cromwell took over but he was not up to the job and by 1660 the Crown was restored to England. It was against this background that in 1663 Isaac Newton graduated but 1665 and 1666 were plague years.

Fig 2.67 Plague 1665.
www.learningcurve.gov.uk
CUT TO

TWO SC 80

Fig 2.68 Newton's Woolsthorpe birthplace.
www.astrosurf.org
CUT TO

This meant that the University had to be closed and Newton spent this time at home in Woolsthorpe, in Lincolnshire. Here he developed his ideas on mathematics.

TWO SC 81

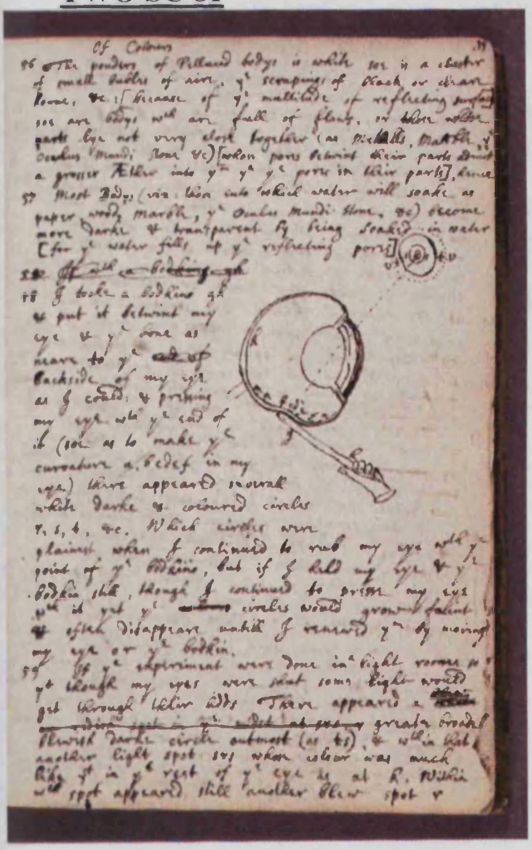


Fig 2.69 Page from one of Newton's notebooks.
www.nypl.org
CUT TO

From his notebooks we can see that he had not been well taught and that he did go on and prove most of the mathematics he knew, for himself. It was after this period of development that he went on to create a field of original mathematics. He invented an area of mathematics that we now call calculus but that he called Fluxions. This was his secret tool that he obtained many results with, but he wrote it down in conventional mathematics.

Two SC 82

WE SEE A MIDDLE-AGED NEWTON SITTING TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN IT SAYS ISAAC NEWTON. HE IS A CLEARLY AN ARROGANT MAN.

It was whilst at Woolsthorpe in this time that I did determine the idea of universal gravitation. I did at once test this matter by analysis of the nature of the motion of the moon around the Earth. I did reason that the moon is like a ball that hath been thrown very hard at the Earth, but the speed at which she is falling is so fast that she keeps missing. I did then reason that the moon must have kept travelling round because the Earth is round. I deduced that the forces, which keep the planets in their orbs, must be reciprocally as the squares of their distances from the centres about which they revolve; and thereby compared the force requisite to keep the moon in her orb with the force of gravity at the surface of the Earth, and found the answer pretty nearly.

Fig 2.70 Newton
www.sprott.physics.wisc.edu

CUT TO

TWO SC 83

In terms of his mathematical ability, Newton was characteristically a modest man. He did some very interesting work on calculating the period of the moon and in fact his calculation of the true period of the moon was close to its true value of about 27.25 days.

Fig 2.71 Newton at 46; Moon at full.
www.ucl.ac.uk

CUT TO

TWO SC 84

In 1667 Newton went back to Cambridge and was made a fellow of Trinity, his Cambridge College. In 1669 he was appointed to a chair of mathematics, the Lucasian Professor of Mathematics, the post that is held by Stephen Hawking today. Newton was only 26 years old.

Fig 2.72 Newton's rooms Trinity College, Cambridge.
www.research.att.com

CUT TO

TWO SC 85

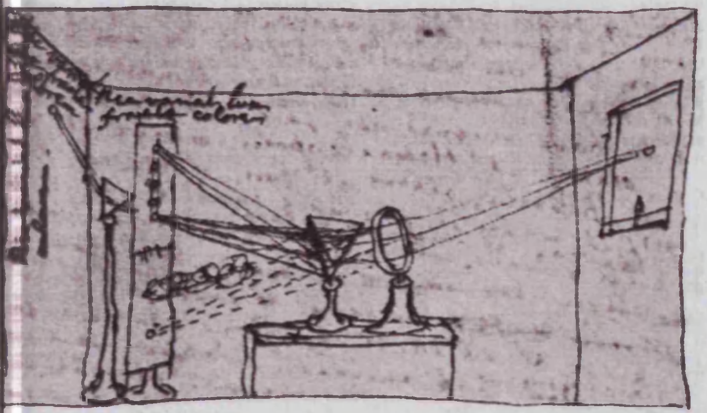


Fig 2.73 A drawing Isaac Newton made of the prism experiment he conducted in his dorm room in Cambridge.
www-psych.stanford.edu

CUT TO

He began his work at Cambridge by thinking about light and the nature of light. This was not a man who indulged in idle speculation. The work he set himself was to attempt to solve the contemporary problems of the day and light was one of these problems.

TWO SC 86

Fig 2.74 Isaac Newton's telescope.
www.museum.vic.gov.au

CUT TO

At this time England was a seafaring nation, so it made sense for Newton to work on light. The use of light was important because of the need for the use of a telescope, a vital tool on board a ship.

TWO SC 87

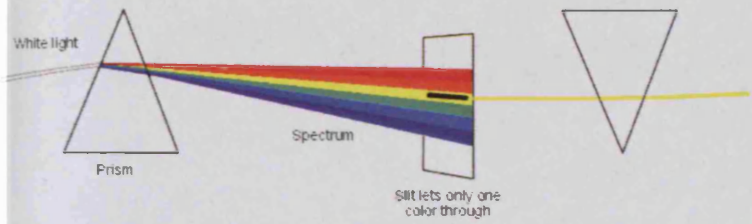


Fig 2.75 Triangular chunk of glass.
www.astrophys-assist.com
CUT TO

V/O NEWTON'S VOICE
I procured me a triangular glass prism, to try therewith the celebrated Phenomena of Colours. In order thereto, I did darken my chamber and made a small hole in my window shuts to let in a convenient quantity of sunlight.

TWO SC 88

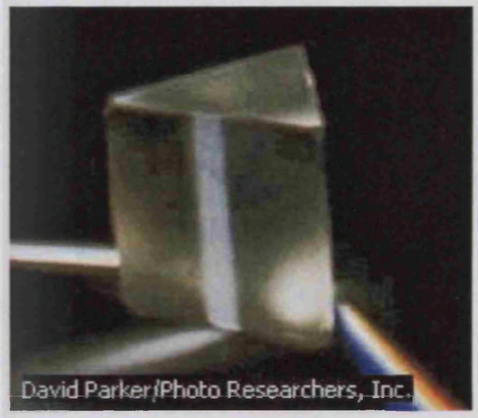


Fig 2.76 Through a triangular glass prism.
www.library.thinkquest.org
CUT TO

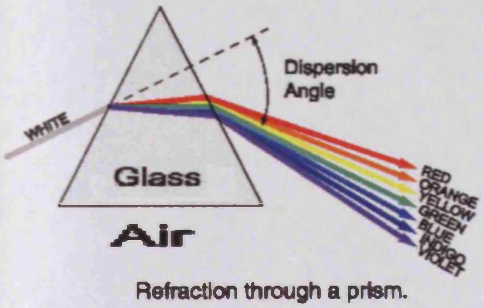
NEWTON V/O CONTINUES.
I placed my prism at his entrance, that it might be therefore refracted to the opposite wall. It was at first a very pleasing divertissement to view the vivid and intense colours thereby. After a while applying myself more circumspectly, I became surprised to see them in an oblong form, which according to the received laws of refraction, I expected should have been circular.

TWO SC 89

Fig 2.77 Light refraction through a prism.
www.seismo.unr.edu
CUT TO

Newton experimented with colour and found that when light was passed through a prism it was split into a spectrum of colours

TWO SC 90



2.78 Refraction through a prism.
www.library.thinkquest.org
CUT TO

Here is the same thing in diagrammatic form. Traditionally it had been thought that the passing of the light through glass actually modified the light. Newton proved this was not the case. Were this to be true, then as the light passed through a second prism, then further colours should be produced. This does not happen.

TWO SC 91

This simple yet crucially important experiment came at a time when the world was developing more colours for use in everything and there was great demand for knowledge of colour. This was also one of the many rows that were to surround Newton.

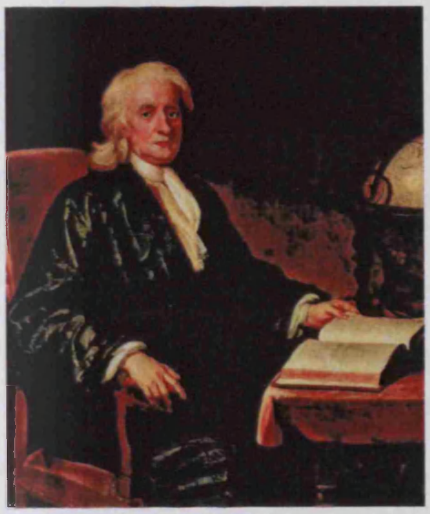
Fig 2.79 Introduction to the Bases of Colour.
www.psych.ucalgary.ca
CUT TO

TWO SC 92

Newton had shown that light was not modified when it passed through a glass prism; it was physically separated. Whilst this may seem straightforward to us, it is in effect a new concept in the explanation of natural phenomena and one that his contemporaries found quite inaccessible. Robert Hooke argued with him and eventually Newton tired of the whole situation. He wrote of his frustration to Leibniz, the well-known German mathematician.

Fig 2.80 Robert Hooke.
www.vitruvio.imss.fi.it
CUT TO

TWO SC 93



WE SEE NEWTON SITTING AT HIS DESK.
'I was so persecuted with discussions arising from the publication of my theory of light, that I blamed my own imprudence for parting with so substantial a blessing as my quiet to run after a shadow.'

Fig 2.81 Isaac Newton at his desk.
www.linux-magazin.de
CUT TO

TWO SC 94

From that time he really refused to have anything to do with any type of debate and it is significant that he did not publish his book on Optics until 1704, the year after Hooke died. His stubbornness as a man does not overshadow his contribution to the subject.

Fig 2.82 Isaac Newton.
www.historyguide.org
CUT TO

TWO SC 95

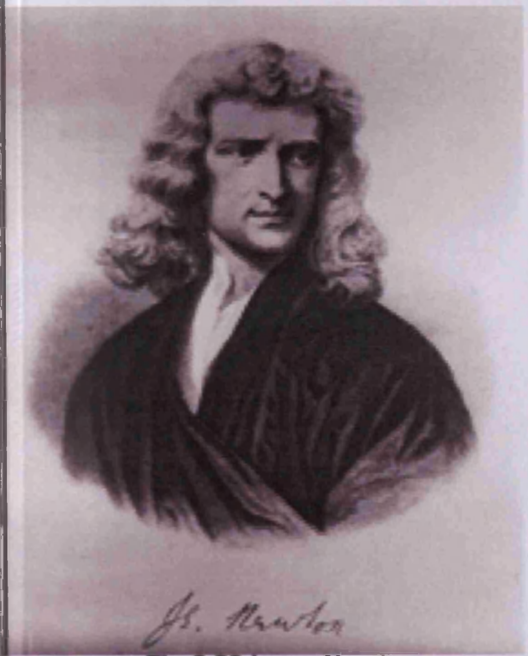


Fig 2.83 Isaac Newton.
www.pbs.org

Newton had shown us the power of the mathematics. His use of mathematics to understand the world was possible because astronomy was the first science where accurate measurements could be made. Newton took all of the data known about the orbit of the planets, and there was a lot of data from measurements that had been made over centuries, and brilliantly decanted it into one single law of nature where the force that exists between two objects is dependent on how heavy they are and on the inverse square of the distance between them. This law has become known as the inverse square law. It meant that the mathematical description of the state of the planets and their orbits made it possible to predict the positions of the planets in the future and it showed that the law of nature that held the planets on course was the same law that holds us on the planet and made the famous apple fall to earth, the law of gravity.

CUT TO

TWO SC 96

Newton had uncovered the key to the clockwork mechanism of the heavens and how it worked. This was the mark of his greatness.

Fig 2.84 The clockwork universe.
www.physicalworld.org

CUT TO

TWO SC 97

Fig 2.85 Newton's statue at Cambridge..
www.cambridge2000.com

Newton began to develop a reputation both in Cambridge and in London and this led to new controversies. It was the custom of the time to present one's work in papers that were passed around amongst contemporaries.
This Newton did and it led to a bitter row between him and Leibniz over the development of the part of mathematics that deals with rates of change, calculus. Newton simply did not believe that Leibniz could develop it independently.

CUT TO

TWO SC 98

Fig 2.86 Gottfried Wilhelm Leibniz.
www.lacentral.com

But there is no doubt that Leibniz himself was a highly respected mathematician and that he most certainly did develop calculus independently.

CUT TO

TWO SC 99

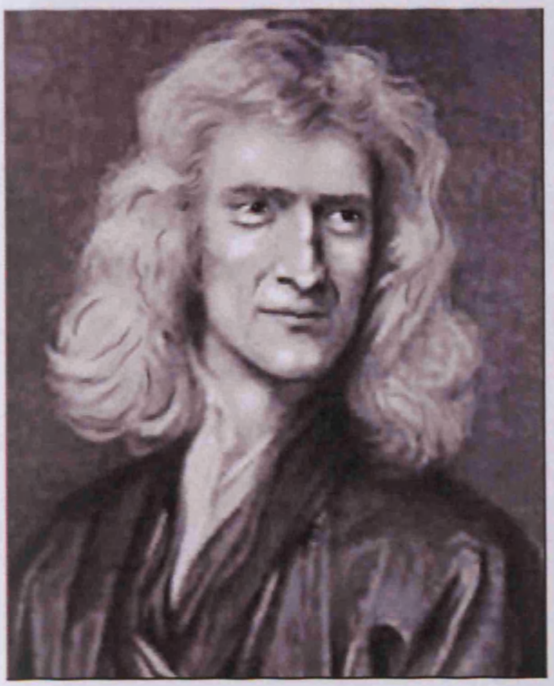


Fig 2.87 Sir Isaac Newton.
www.lucidcafe.com

CUT TO

These incessant arguments do appear to have tired Newton and he did consider retiring altogether from this public role in justifying and explaining science and confining himself to his cloister in Trinity College. After all, he had his own laboratory and his own small garden, but in the end he seems to have reasoned that if he refused to go to London to meet with scientists, then they would simply come to Cambridge and put their arguments to him there.

TWO SC 100

Fig 2.88 Edmund Halley.
www.nationalarchives.gov.uk

CUT TO

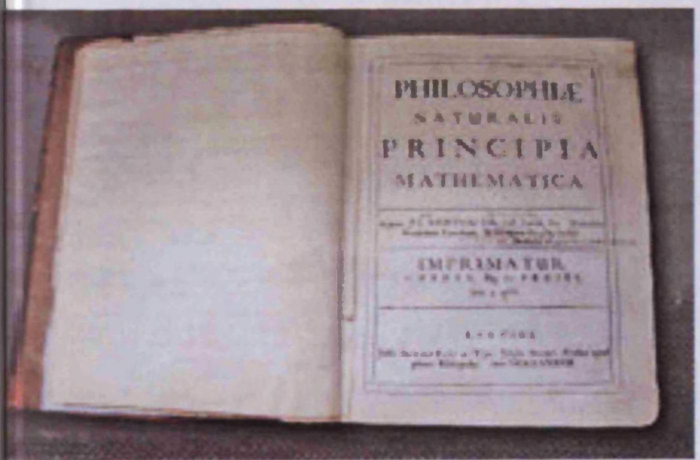
For instance, in 1684, another row broke out, this time between Robert Hooke, Sir Christopher Wren and the young astronomer Edmund Halley. This led to Halley visiting Cambridge to see Newton to seek his advice and it was afterwards that an off the cuff comment revealed both the character and genius of Newton.

TWO SC 101

V/O HALLEY
'After we had been some time together, I did venture to ask him what he thought the curve would be that would be described by the planets supposing the force of attraction from the sun to be reciprocal from the square of their distance from it. He did immediately and without any thought reply that it would be ellipsis.
(LAUGHS AT THE THOUGHT)
I did then say to him,
My dear sir, how is it that you have most certain knowledge of this?
Whereupon he looked at me most indignantly and said,
I have calculated it'.

Fig 2.89 Edmund Halley.
www.astrosurf.org
CUT TO

TWO SC 102



In 1687, Newton published the 'Principia, the Mathematical Principles of Natural Philosophy'. This was his most famous work and contained the laws of motion, which was published in three volumes. The work itself owed much to Galileo, and Newton acknowledged this, but what is most important to us is that it was based on the same scientific philosophy.

Fig 2.90 Newton's Principia.
www.en.wikipedia.org
CUT TO

TWO SC 103

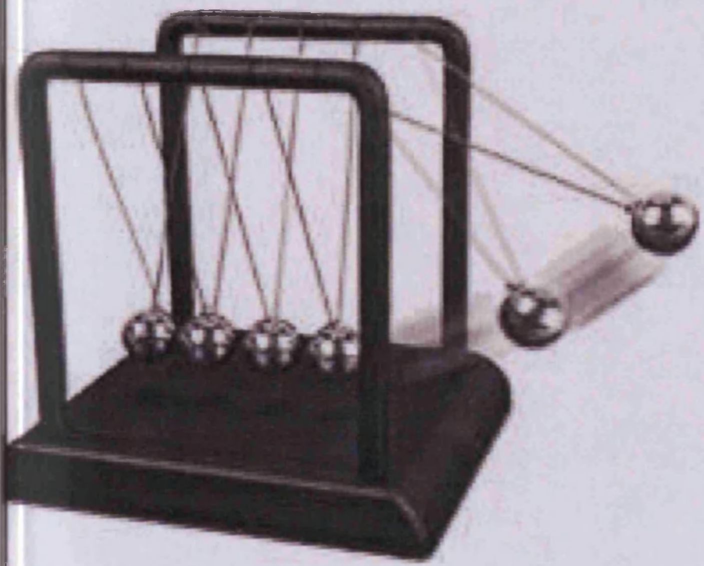


Fig 2.91 Newton's cradle.
www.colorado.edu
CUT TO

In the book Newton reduced all motion to three universal laws: first, a body at rest remains at rest, unless acted upon by a force; then its acceleration is proportional to the force that is acting; and the third law said action and re-action are equal and opposite.

TWO SC 104

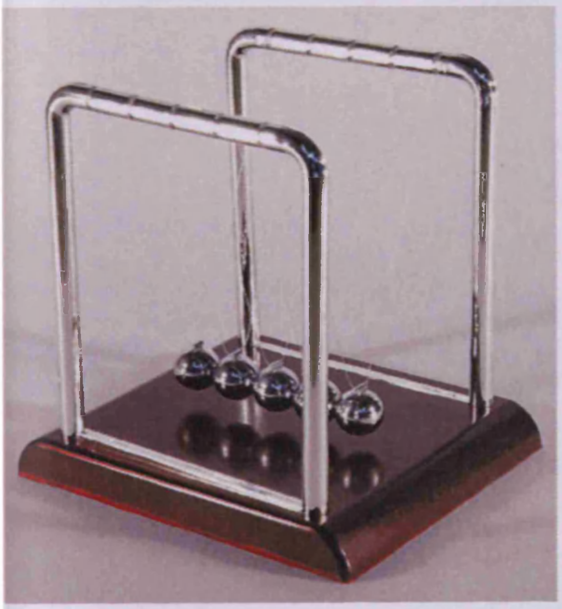


Fig 2.92 Newton's Cradle desk toy.
www.electix.nl
CUT TO

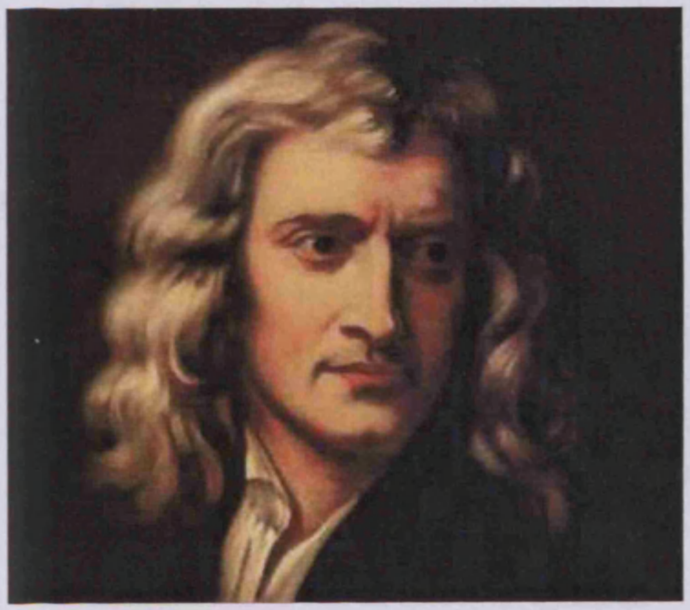
Newton also showed that Kepler's Laws of Planetary Motion flow from these laws, together with the inverse square law of gravity. But the truly sensational aspect of Newton's work was the fact that it was universal.

TWO SC 105

Regardless of where you are in the universe, every particle of matter attracts every other particle of matter according to the same law. Newton had encapsulated the mechanisms of the universe in three mathematical statements that were true in all cases and, perhaps even more surprisingly, they were simple.

Fig 2.93 Outer space.
www.jiskha.com
CUT TO

TWO SC 106



Newton V/O
I did take up the explanations in my first two volumes and enhance their understanding in volume 3. My purpose here was quite simply to demonstrate the system of the world and this I did.

Fig 2.94 Isaac Newton.
www.biografiasyvidas.com
CUT TO

TWO SC 107

Fig 2.95 Palace of Westminster.
www.explore.parliament.uk
CUT TO

In June 1714 a Parliamentary committee assembled at Westminster Palace in London, to try and answer the merchants and the seaman's petition pressing for action over Longitude: the need to locate one's ship at sea. They immediately sought advice from Newton, by then an old man of 72, and his now friend Edmund Halley. Newton prepared written remarks for the day, which he read aloud to the committee and also took questions. His summary suggested that whilst all of the proposed methods of finding longitude were theoretically possible, they were difficult to execute in practice.

TWO SC 108

Fig 2.96 Isaac Newton.
www.telosnet.com
CUT TO

WE SEE NEWTON TALKING TO THE UNSEEN INTERVIEWER

'One method is by a watch, to keep time exactly. But by reason of the motion of the ship, the variation of heat and cold, wet and dry and the difference of gravity at different latitudes, such a watch hath not yet been made.'

TWO SC 109

He would also go on to mention the potential but still problematic astronomical solutions being offered and so on July 8 1714

Fig 2.97 ngc281FRGB01web.
www.heavensgloryobservatory.com
CUT TO

TWO SC 110

the Longitude Act was issued. It encouraged Parliament to welcome solutions from scientists, artists or individuals or groups from any nation and to reward them for their efforts, most handsomely.

Fig 2.98 The Longitude Act.
www.arte-tv.com
CUT TO

TWO SC 111

£20 000 was on offer for a method that determined the longitude to an accuracy of half a degree. £15 000 was on offer for a method that determined the accuracy to within two-thirds of a degree, and £10 000 was on offer for a method that was accurate to within one degree.
But why was it so vital to have such close accuracy?

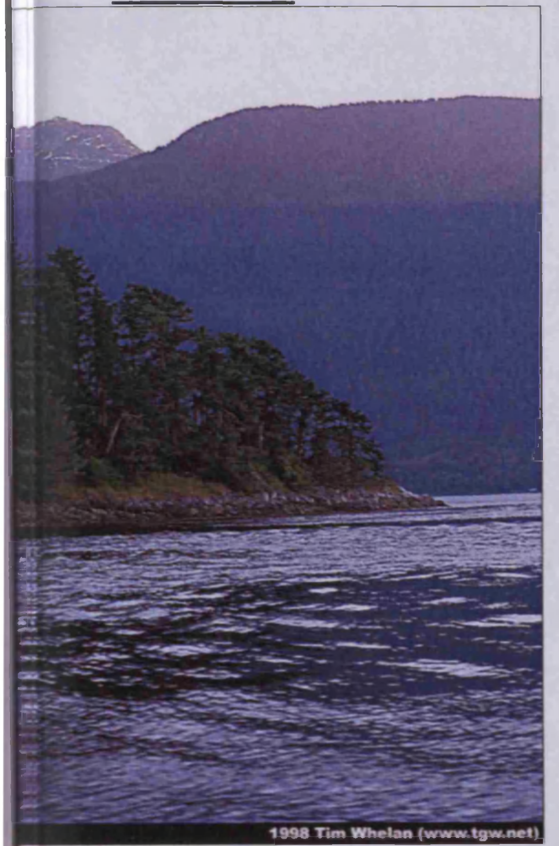
Fig 2.99 Money falling from the sky.
www.fotosearch.de
CUT TO

TWO SC 112

One degree of latitude covers sixty nautical miles over the surface of the globe at the equator, so you can see that to be out by just a fraction of a degree was, as mathematicians put it, significant. In reality you could be a large distance away from the spot you thought you were in. For a ship on the high seas, this could literally mean the difference between life and death.

Fig 2.100 Ocean.
www.web.media.mit.edu
CUT TO

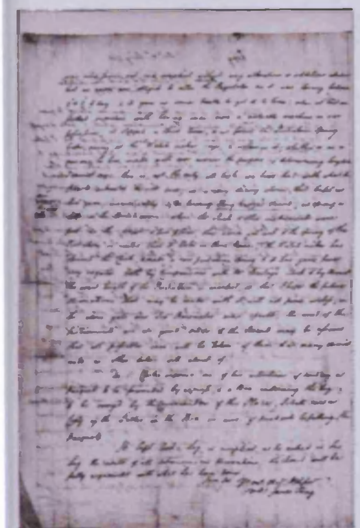
TWO SC 113



So one degree out could means 60 nautical miles out, but the fact that the government were prepared to accept this is a measure of the desperation of the time.
Longitude is the angular distance east or west from a standard meridian such as Greenwich, to the meridian of any other place. So this means that when trying to navigate across an open ocean, the ability to calculate longitude is vital and mistakes were often made as we saw with Clowdisley Shovell. Early sailors knew that for every fifteen degrees travelling eastward, the local time moves forward one hour. Similarly for every fifteen degrees travelled westward the time moved back one hour. So they knew that if they had the local time at two points, they could calculate the difference between them to calculate the longitude. But it wasn't that easy. Although they could measure the local time by observing the sun, sailors also needed to know the time at a reference point like Greenwich. But at that time they only had pendulum clocks, which were rendered hopelessly inaccurate by the motion of the sea.

Fig 2.101 One nautical-mile ahead.
www.tgw.net
CUT TO

TWO SC 114



The Longitude Act established a panel of judges who were known as the Longitude Board. The Board was made up of notable men and was empowered to give incentive awards to poor inventors, with the hope of bringing good ideas forward and into development.
This is where the silly season began.

Fig 2.102 Board of Longitude.
www.image.sl.nsw.gov.au
CUT TO

TWO SC 115

Fig 2.103 Model ship.
www.hobbyplace.com
CUT TO

One proposed solution was that ships should be anchored at various stages across the Ocean and fire a cannon ball every hour. A ship in transit would therefore simply need to follow a pre-determined path and listen for cannon shot. There appears to have been little thought given to the mental and physical health of those sailors who would be required to man these ships.

TWO SC 116

Fig 2.104 Newton.
www.sprott.physics.wisc.edu
CUT TO

Newton himself began to become very tired of the ideas that were put forward. Newton was convinced the answer lay in the stars. A method called the Lunar Distance method had been proposed many times over the preceding centuries and was gaining credence as astronomy improved. Newton died in 1727 and therefore never lived to see an unknown watchmaker emerge 40 years later, with a solution.

TWO SC 117

Fig 2.105 House Plaque.
www.answers.com/topic/john-harrison

CUT TO

John Harrison had been born on March 24, 1693 in Yorkshire England. He was the eldest of five children. Very little is known of his early life.

TWO SC 118

Fig 2.106 Trinity Church Barrow-upon-Humber.
www.uktouristinfo.com

CUT TO

At about the age of 4, the whole family moved some sixty miles to Lincolnshire, to a small village called Barrow-on-Humber.

TWO SC 119

It was here that he learned to work wood.

Fig 2.107 Wooden products.

www.smithstuff.net

CUT TO

TWO SC 120

It was also here that his craving for book learning was recognised. He had already taught himself to read and to write when a visiting clergyman recognised the eagerness and will to learn and lent him a book of science lectures by the mathematician Nicholas Saunderson of Cambridge University.

Fig 2.108 Antiquated, antique, book.
www.istockphoto.com

CUT TO

TWO SC 121

Fig 2.109 Wooden clock details.
www.clockmaker.it

CUT TO

He wrote out every word and copied every diagram to improve his understanding of motion. He read and re-read his notes many times over the next few years, adding marginal notes and insights as he did so. He built his first clock in 1713, before he was twenty years old.

TWO SC 122

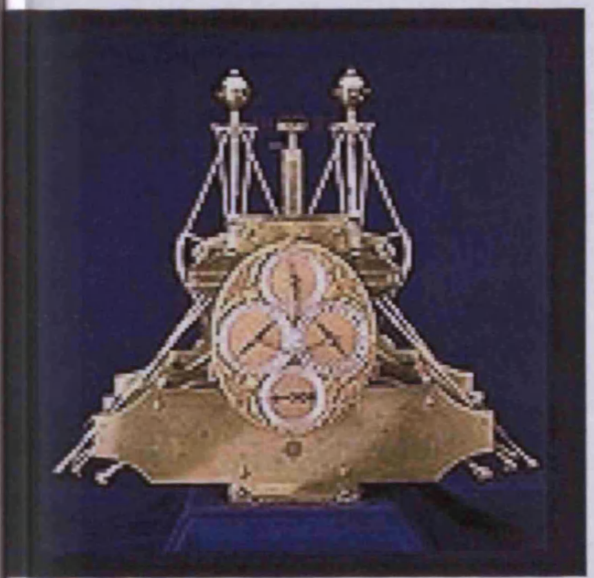


Fig 2.110 John Harrison's first clock H 1.
www.voanews.com/specialenglish/ images/esa.int clock

CUT TO

Here it is, in the Worshipful Company of Clockmakers, Museum at Guildhall in London. And as you can see, it is made almost entirely of wood. Harrison was a carpenter; he understood wood so it really should be no surprise to us that he chose to work in wood.

TWO SC 123

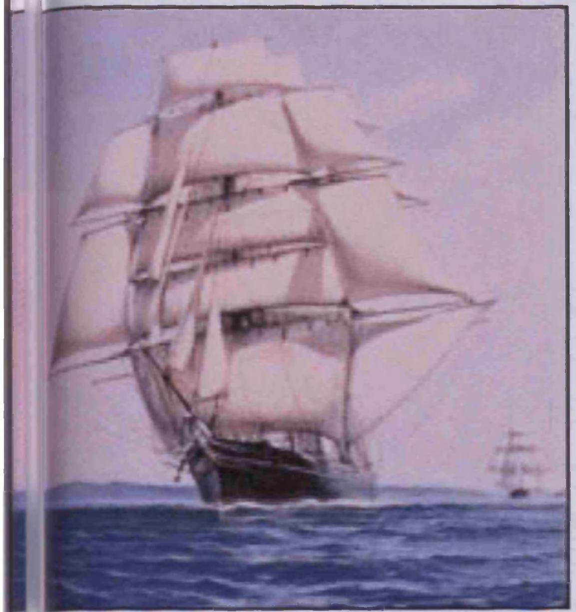


Fig 2.111 The Cutty Sark.
www.ageofsail.net/ images/004-03.
CUT TO

Longitude was the great technological challenge of his age but we are not really sure how Harrison came to be involved. It has been suggested that the fact that Hull was a busy port would have been enough for all people like him who lived close by, to hear of the awards on offer.

TWO SC 124

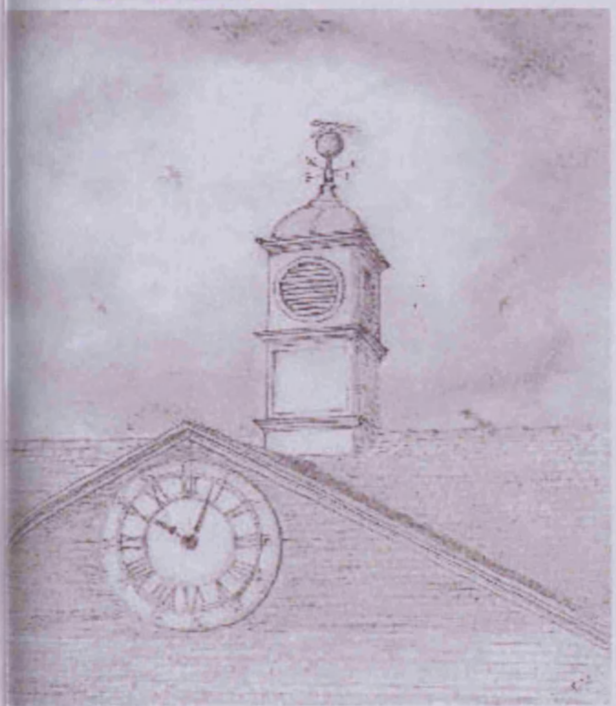


Fig 2.112 Sketch of Brocklesby Park Stable Block Showing Harison's clock.
www.homepage.ntlworld.com
CUT TO

Harrison developed something of a reputation as a clockmaker in the area and around 1720, Sir Charles Pelham commissioned him to build a tower clock above the stable at Brocklesby Park. Here it is and it is all made of wood. The clock was so well designed it didn't even need oiling. This is because the parts that normally are oiled were made from a tropical hard wood that gives off its own grease. Harrison avoided metals in this area because of the dampness in the air. When he did use metal, he made sure it was brass. And the clock is still working. Apart from a short time in the 19th Century when it was stopped for re-furbishment, it has never stopped working. This is the mark of his great skills.

TWO SC 125

Harrison knew that the crackpot ideas that had abounded over longitude meant that the board had never met in the fifteen years. He therefore went to Greenwich where he met with Edmund Halley.

Fig 2.113 Edmund Halley.
www.atschool.eduweb.co.uk

CUT TO

TWO SC 126

V/O HALLEY

'I must confess that it did vex me at first to be entreated in such a manner by this man. For it was the case that I along with many others had been searching with much diligence for an answer in the stars. It made sense to me that to determine one's position one had to establish the position of the stars and replicate that knowledge on earth as it is in heaven. Yet this man from Lincolnshire had contrived to do so without any of the intellect that, may I say others and I had injected, instead he had used his own form of intellect. I did marvel at the quality of his drawings yet I knew that the board would not entertain his approaches so I did resolve to send him to Mr Graham, since he is a most refined watchmaker.'

CUT TO

TWO SC 127

Fig 2.114 George Graham.
www.scienceandsociety.co.uk

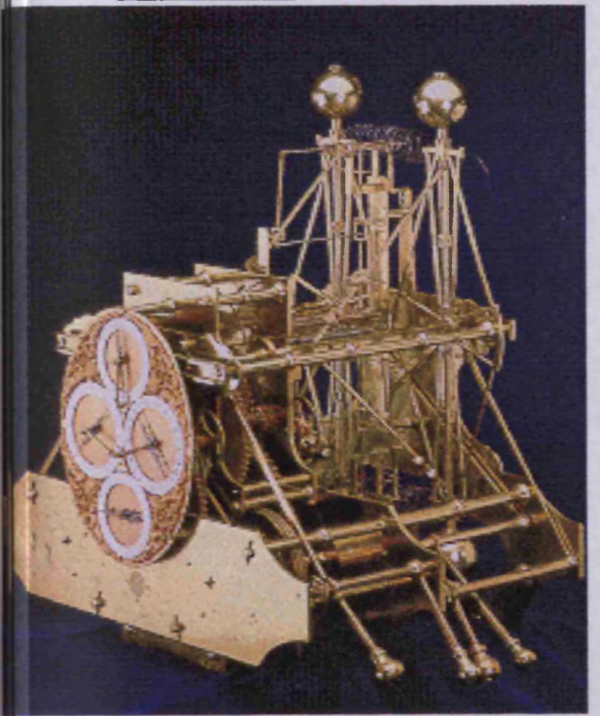
V/O George Graham

'I did receive Harrison at 10 o'clock in the morning and did find him a rough type. I think it was in response to the manner in which I had treated him. But I did find in him a man of great curiosity and intellect. He was not schooled in the ways of gentlemen but rather he was a man to whom England could turn to solve its problems. I would that there were more like him to day yet I fear that they would be unable to enjoy equality of esteem, such is the nature of our society. Whereas we should strive to include, all too often we strive to exclude.

The quality of his work was most impressive to me, with fine drawings. Well, indeed, by the end of the day I did entreat him to join us for dinner and at night he did return to Lincolnshire with my blessing and a loan to finance the work that he had so studiously started. This was the most marvellous of days for me.'

CUT TO

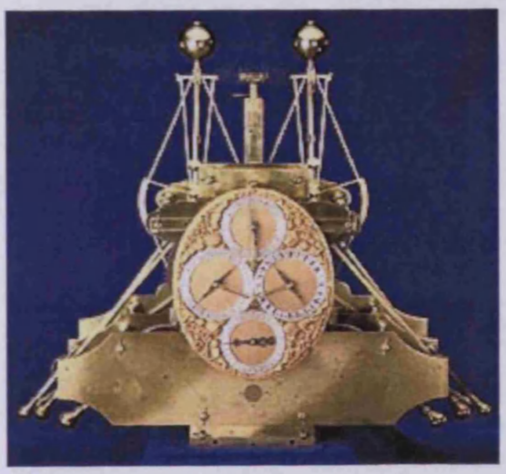
TWO SC 128



Harrison spent the next five years perfecting his longitude clock and there were others to follow. This one became known as the H1 and it is housed in the British National Maritime Museum in Greenwich in the UK. It is wound daily and still runs beautifully.

Fig 2.115 H1 c Harvard College Press.
www.inference.phy.cam.ac.uk
CUT TO

TWO SC 129



On June 30 1737 for the first time it its 23-year history, the Board of Longitude met. The clock had undergone sea-trials and was a major success, having lost only a few seconds on a trip to Portugal and back.

Fig 2.116 John Harrison's H1.
www.24hourmuseum.org.uk
CUT TO

TWO SC 130

Fig 2.117 John Harrison's H4 Chronometer.
www.24hourmuseum.org.uk
CUT TO

There followed a series of clocks because in many ways Harrison was his own worst enemy, always seeing the negative in his clocks. However, H1 was a masterpiece and did answer the need of the time, but it wasn't until 1759 when he finished H4 that he ultimately won the longitude prize. And H4 now lies in an exhibit case at the National Maritime Museum. Harrison's design of balance and counter balance was so good that Captain Cook on his second voyage in 1772 took a copy of H4 called K1. Cook returned in July 1775, during the three-year voyage K1 had never been inaccurate by more than 8 seconds. And it was a clock that was to affect another young man, in Switzerland.

TWO SC 131

Fig 2.118 Berne, Switzerland.
www.jefflewis.net
CUT TO

It was here in Berne Switzerland that a young man came to live and work, in 1900.
He worked in the Patent Office and every day got off the tram near the clock tower. It was this clock tower and his thinking that was to revolutionise the world. His name was Albert Einstein.

TWO SC 132

Fig 2.119 Albert Einstein 1879-1955.
www.ethbib.ethz.ch
CUT TO

Einstein had a very simple, almost childlike way of looking at things; however, the answers to his questions were extremely profound. In his teens he asked himself, ' What would the world look like if I rode on a beam of light?'

TWO SC 133

Fig 2.120 Berne clock tower.
www.pbs.org
CUT TO

Look at the clock here. It is the actual clock that Einstein used when starting to think about relativity. It is the clock tower in Berne. Imagine it shows noon. Now, if I am on a beam of light when I leave, I travel at 186 000 miles per second away from the clock. This ought to take 1 second. But when I look at the clock it still shows noon because the beam of light that brings the information of the state of the clock face to me, is also the beam I am moving on. So as far as I can see it, I have cut myself off from the passage of time.
As I travel on this beam of light, I am alone in my time and space that is increasingly leaving the norms left behind me.

TWO SC 134

What does this tell us? One thing is that time is not universal. But there is a more subtle difference between me on the light of beam and a person stood at the base of the clock tower in Berne.
The experience for us both is different; each of us has our own path.

Fig 2.121 The clock that Einstein looked at.
www.ironic.com
CUT TO

TWO SC 135

On my beam of light, my experiences are consistent. I discover and use the same laws of mathematics. I have the same relationships between speed, distance and time, mass and force that the man at the base of the clock tower gets, but, and this is the important point, the values I get on my beam of light are not the same as the values he gets at the base of the clock tower. This is the kernel of the principle of relativity.

Fig 2.122 Einstein Pocket Watch.
www.oddbox.com
CUT TO

TWO SC 136

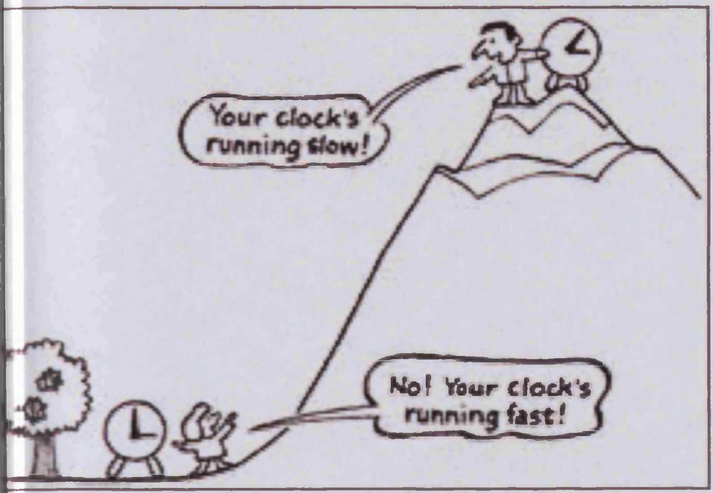


Fig 2.123 Einstein relativity and time.
www.npl.co.uk
CUT TO

So, what is it that keeps my world together on the beam and his world together at the base of the clock tower? The answer is the passage of light. Light is the natural phenomenon that carries information that binds us altogether. Information always passes between us at the same speed. We always get the same value for the speed of light. This means that time, space and mass must be different for each of us because they have to give the same laws for me on the beam as for the man at the base of the clock tower, consistently, yet have the same value for the speed of light.

TWO SC 137

Fig 2.124 Creating ripples in a pond.
www.utexas.edu
CUT TO

Light and other radiations are signals that spread out from a source like ripples through a universe. There is no way in which news of the event can move out faster than it does. The signal, whether it is light or an x-ray or a radio wave, is the ultimate transporter of news or messages and forms a basic network of information through which the material world is totally linked together.

TWO SC 138

Fig 2.125 Big-Ben.
www.londongeneral.co.uk

CUT TO

Even when the message is time, we simply cannot send the message from one place to another faster than the light or radio wave that carries it.

TWO SC 139

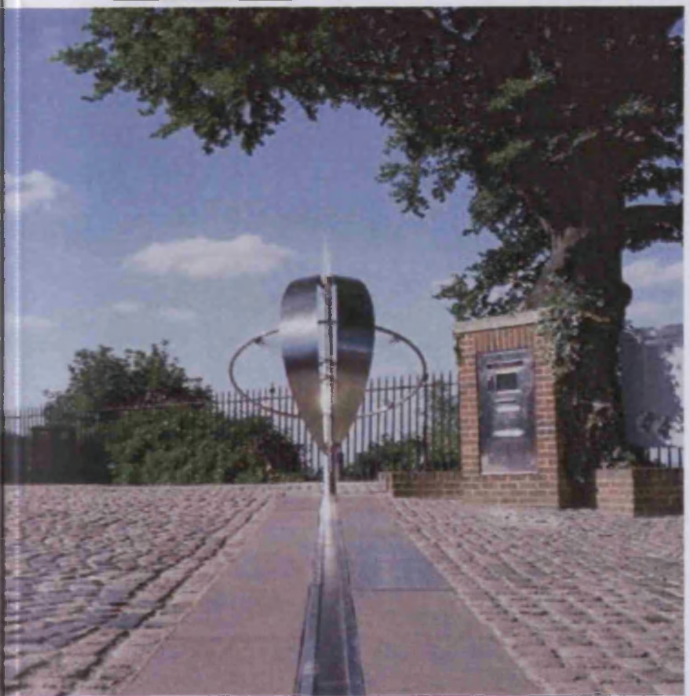


Fig 2.126 The Greenwich Meridian Line.
www.portcities.org.uk

CUT TO

There is no universal time in the world by which we can set clocks without including the speed of light in there somewhere. Every time a signal is sent from here in Greenwich, it involves the speed of light.

TWO SC 140

Fig 2.127 Isaac Newton.
www.eia.doe.gov
CUT TO

In essence, what Einstein did was to change our view of the world. For Newton, space and time had been absolutes. Newton had a mechanistic framework in which time and space were the constructing pillars. Newton 's world is a God's eye view of the world. Regardless of where the observer is, or how he travels, the world looks the same.

TWO SC 141

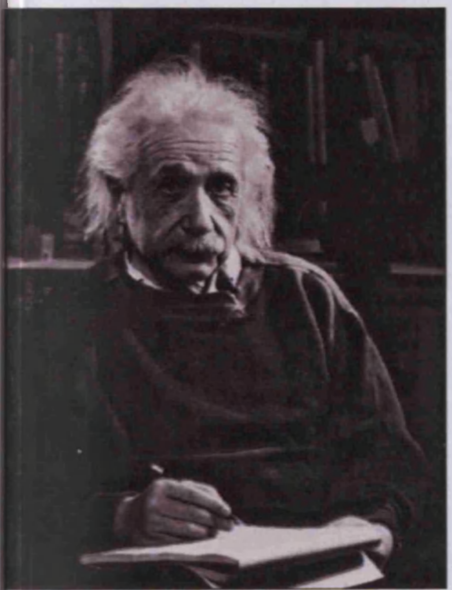


Fig 2.128 Albert Einstein.
www.biografiasyvidas.com
CUT TO

What Einstein tells us, is that Newton's view is wrong. In Einstein's world, we have a people view of the world. What each of us sees is relative to each of us in terms of our location and speed and this relativity cannot be removed. It is impossible for us to know what the world is like in itself. The only way we can compare what it is like for each of us is by exchanging messages. I on my beam of light and you at home cannot share a divine instant view of events. We can only communicate our experiences to one another and this very act of communication takes time. It is this time lag that occurs in all signals that is set by the speed of light.

But what was it that drove Einstein? It appears to have been his insatiable curiosity. Physics is not events; it is a set of observations of the natural world. Relativity is the understanding of the natural world as a set of relations.

TWO SC 142

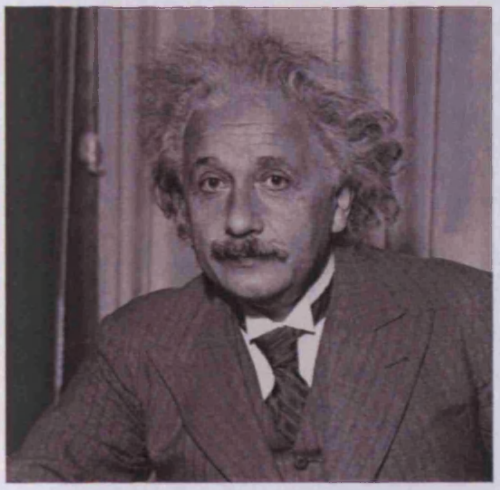


Fig 2.129 Albert Einstein.
www.mediatheek.thinkquest.nl

EINSTEIN V/O
I want to know how God created this world. I am not interested in this or that phenomenon, in the spectrum of this or that element. I want to know His thoughts; the rest are details.

CUT TO

TWO SC 143

Fig 2.130 Einstein.
www.twoday.net

Was Einstein a genius? Well, undoubtedly yes. In 1905 he was a humble patent clerk. At the age of 26 he sent three papers that he had written in his spare time, to the premier journal 'Annalen der Physik'. In his submission he asked for them to be published, if there was room. They were published in the same issue and they did what he imagined they would do - they changed our view of the world in which we live.

One paper was an update of Planck's quantum theory of radiation. In this Einstein declared that light travels as both a wave and as particles called quanta, because he said, it had to. In the second paper he, the patent clerk, explained the then unexplained phenomenon of Brownian motion, and the third paper was the piece de resistance, relativity. Later Einstein would write modestly to a friend that it modified the theory of time and space.

CUT TO

Two Sc 144

So we have seen how contemporary needs drives the search for solutions. This is true at any time in history. Whenever problems are faced, mathematics and science are usually the tools used to at least try and solve those problems.

Fig 2.9 Grave of Rear Admiral Shovell
www.submerged.co.uk/ association.php
CUT TO

Two Sc 145

We've also seen how zealots can challenge the truth through bigotry.

Fig 2.47 Trial of Galileo Galilei.
www.law.umkc.edu
CUT TO

Two Sc 146

Finally we have also seen how asking simple questions

Fig 2.119 Albert Einstein 1879-1955.
www.ethbib.ethz.ch
CUT TO

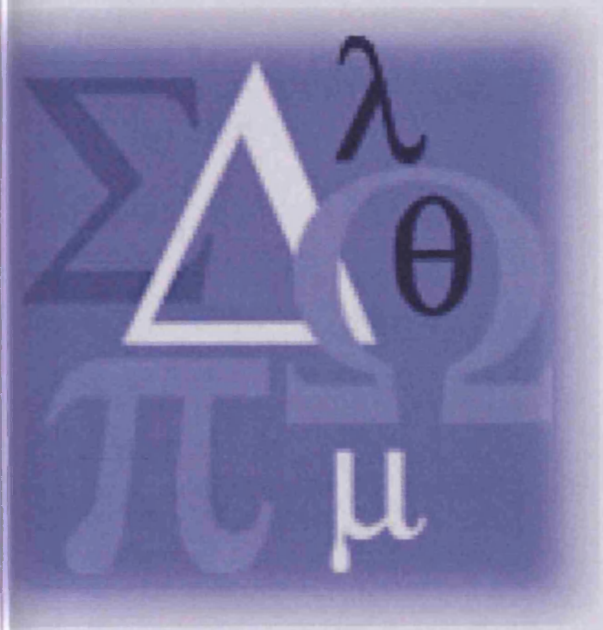
Two Sc 147

can change our understanding of the universe in which we live.

Fig 131 Universe.
www.samueljscott.wordpress.com

CUT TO

TWO SC 148



So what of the future? Are we at an end of using the mathematics of the skies to further developments here on the earth?
Far from it.

Fig 2.132 Mathematics.
www.jiskha.com
CUT TO

TWO SC 149

Scientists are already working on modes of transport that will replace supersonic flight. In our children's lifetimes it may be possible to travel from London to Sydney in 2 hours or less.

Fig 2.133 Concorde.
www.ciel.me.cmu.edu
CUT TO

TWO SC 150


Fig 2.134 Telescopes.
www.ulo.ucl.ac.uk

Travel to other planets like Mars will happen and all because of the work of men like Harrison, Newton and Einstein.
Every age has its problems that it needs people to solve. The experts of the future will take us to places that are only limited by our imagination. There are challenges that lie ahead and we will need to be astute enough to tackle them. Looking upwards, with mathematics in mind, to the heavens will solve many of the problems of the future.

FADE TO CREDITS

Programme Three

The Language of the Universe

Enigma Variations

<u>THREE SC 1</u>

WE SEE A WOMAN DRESSED IN 17 TH CENTURY CLOTHES ENTER A ROOM WHERE A CRIMSON VELVET CHAIR IS VISIBLE AND A THRONE IS AT THE OPPOSITE END OF THE ROOM. ON THE SCREEN, IT SAYS FOTHERINGAY CASTLE SATURDAY 15 OCTOBER 1586. WE SEE HER WALK TOWARDS THE THRONE BUT SHE IS THEN GUIDED AWAY TO THE CHAIR.THE TEXT ON THE SCREEN BECOMES JUMBLED AS IN A CODE AND THEN UNRAVELS TO SAY 'THE TRIAL OF MARY QUEEN OF SCOTS'

Fig 3.1 Mary Queen of Scots
www.lawcastle.com

The history of mathematics is full of strange stories, like how algebra, or more correctly cryptology, led to a Queen being executed. It happened in the autumn of 1586 when Mary Queen of Scots entered the courtroom at Fotheringay Castle. She was mistaken in thinking that the throne was for her; it was a symbol of the absent queen. Mary was on trial for treason. She stood accused of plotting against the Queen of England, Elizabeth the First.

<u>CUT TO</u>

THREE SC 2

Fig 3.2 The Crown Jewels
www.geocities.com

It was said that her purpose in plotting against Elizabeth was to take the crown of England for herself, a crime that she denied all knowledge of, but her adversary was a highly intelligent, diligent servant of Elizabeth, a man called Sir Francis Walsingham.

CUT TO

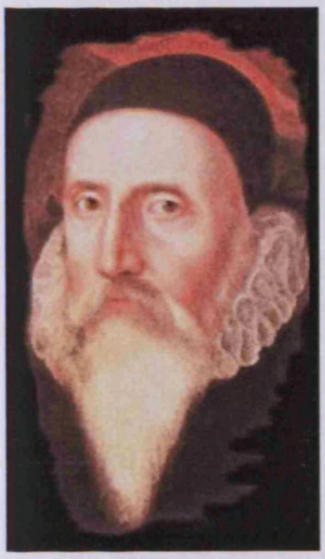
Three SC 3

Fig 3.3 Sir Francis Walsingham
www.tudorplace.com.ar

Walsingham was Elizabeth's principal secretary but he was also her spymaster. He ran a network of spies all over Europe and had one spy called Dr John Dee.

CUT TO

THREE SC 4
V/O IS DEE



WE SEE A MAN WITH A LONG BEARD ADDRESS THE CAMERA DIRECTLY.
I did seek to serve Her Majesty well and did devise a mechanism whereby I could send messages directly to her. To signify such messages were for her eyes only, I did devise a code, which was used to signify this and it was thus: an elongated 7 over two zeroes to represent her Royal and Blessed eyes.

Fig 3.4 Dr. John Dee
www.hants.org.uk

HE DRAWS A SYMBOL ON PAPER AND TURNS IT OVER SO THE CAMERA CAN SEE. IT HAS TWO ZEROES AND AN ELONGATED 7 OVER THEM. IT READS AS 007.

CUT TO

THREE SC 5

Walsingham had by this time arrested all of the other conspirators involved in the plot to depose Elizabeth and replace her with Mary. He had in fact extracted confessions from them and then put them to death. However, he knew he had to be very careful with the way he presented the facts to the Queen. Although Elizabeth clearly despised Mary, executing a Queen is a dangerous business.

Fig 3.5 Sir Francis Walsingham 1532-90
www.history.wisc.edu
CUT TO

THREE SC 6

WE SEE WALSINGHAM IN A PRIVATE ROOM WITH ELIZABETH.

ELIZABETH
My Lord Walsingham, I cannot sign this execution without absolute proof of her guilt.

WALSINGHAM
Your Majesty, I am your humble servant and I do entreat you that such evidence doth exist.

ELIZABETH
You are aware, are you not my Lord, that my Cousin Mary is Queen of Scots. There are those that question the legality of this court in putting to death the head of a foreign state.

WALSINGHAM
It is true, as your Majesty says, that there are those who would make such statements, but I must entreat your Majesty that the very throne of England and indeed your very own safety is at risk whilst this woman abounds.

ELIZABETH
Whilst this woman abounds, you say abounds. My Lord has she not been a prisoner for these last 18 years?

WALSINGHAM
Madam, I do entreat you to consider all of the facts. I do have the evidence that she has plotted for your death and her own placement on your throne.

ELIZABETH
And now I am to consider and order her death, the death of my cousin. And what then my Lord? When they have killed one Queen, how much easier it becomes to kill another.

CUT TO

THREE SC 7

Fig 3.6 Queen Elizabeth I
www.marileecody.com

This shows how insecure Elizabeth felt and was one of the main reasons for her reluctance to order Mary's execution. The order would only be given, if Walsingham could prove beyond all doubt that Mary was guilty….. and he could.

CUT TO

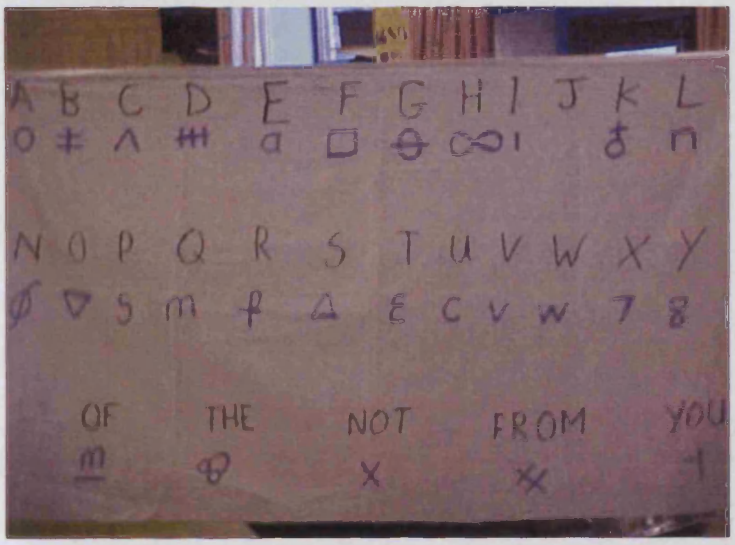
THREE SC 8

Fig 3.7 Mary Queen of Scots
www.maybole.org

Mary was not allowed to have a defence counsel, nor was she allowed help to prepare her case, but she probably felt secure at this stage. She most certainly had been in touch via letter with conspirators but had been careful to use a branch of mathematics that she thought would protect her. She had written her messages in code.

CUT TO

THREE SC 9



Mary was not aware that Walsingham had intercepted all of her letters and she also didn't know that he had access to the best code breaker in England. If the code breaker could decipher the messages between the conspirators, she would have to die and the code break could decipher them.

Fig 3.8 Code used by Mary Queen of Scots
www.sevenhills.leeds.sch.uk

CUT TO

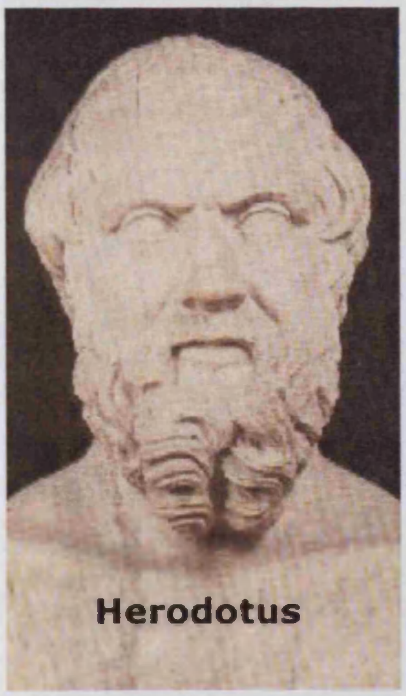
THREE SC 10

Throughout history we have used codes and the part of mathematics called algebra to solve problems, to fight world wars and to carry secret messages. Even today codes are vital for our protection on simple mundane events like browsing the internet.
By the time of Mary's trial in Europe, the use of codes, or cryptography had developed into a growing industry but its history went back a long way. To understand this we really need to go back to the fifth century.

Fig 3.9 Historical Maps of Europe
www.lib.utexas.edu

CUT TO

THREE SC 11
WE SEE A GREEK TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN IT SAYS HERODOTUS, CHRONICLER OF THE FIFTH CENTURY



It came as a surprise to us that Persia intended to attack our armies and lands. An exile called Demaratus did undertake to warn us of the attack. There was only one way in which he could safely get the message across, by scraping the wax off a pair of wooden tablets and then writing on them. He then covered the message with wax again, thus arising no suspicion amongst the guards.

Fig 3.10 Herodotus
www.etsu.edu

CUT TO

THREE SC 12

As a result of this warning, the element of surprise was lost and the Greeks were able to protect their homeland.

Fig 3.11 Ancient Greece
www.shunya.net

CUT TO

THREE SC 13

Fig 3.12 Secret writing
www.jcooperstudio.com

Hiding messages is called steganography and this has been a way of getting information through for centuries.
Invisible writing was one of doing this. Virtually any organic material, even urine, can be used to write messages onto a piece of paper and when dried the message becomes invisible. Then, when the paper is held close to a heat source, the organic material used to make the message singes and becomes visible, revealing the message. The weakness here is that if the message is found, then the contents are easily accessed. On the other hand, cryptography doesn't attempt to hide the message but rather to encrypt the message, that is to make its meaning unintelligible. This is what Mary Queen of Scots had tried to do.

CUT TO

THREE SC 14

Fig 3.13 Chartley Hall and grounds
www.search.staffspasttrack.org.uk

The year is 1586 and Mary is being kept in Staffordshire.

CUT TO

THREE SC 15

WE SEE A MAN ENTERING THE CHAMBER OF MARY QUEEN OF SCOTS. MARY USHERS EVERYONE OUT.

MARY
Master Gifford, you bring us joy, I hope!

GIFFORD
Indeed, I do, your majesty, for I have arranged for many messages from the Kingdom of France to find their way to you and to aid and assist you in all manner of ways to ascend to the throne of England, one that should be rightfully yours.

MARY
Hush, Master Gifford, you must not speak so loudly; my cousin has ears in the most extreme places.

GIFFORD
I humbly crave your pardon, your Majesty, but I writhe in anger every day when I have to know that you are enduring the indignity of this monstrous place when you should be Queen of all of this land, and not that bastard Queen who proclaims against Rome.

MARY
You truly are an honourable servant to your Queen, Master Gifford. Mark you well; you will be amply rewarded for your troubles.

CUT TO

THREE SC 16

How right she was; he was extremely well rewarded but not in the way she had imagined.

Fig 3.14 Mary, Queen of Scots
www.pbs.org

CUT TO

THREE SC 17

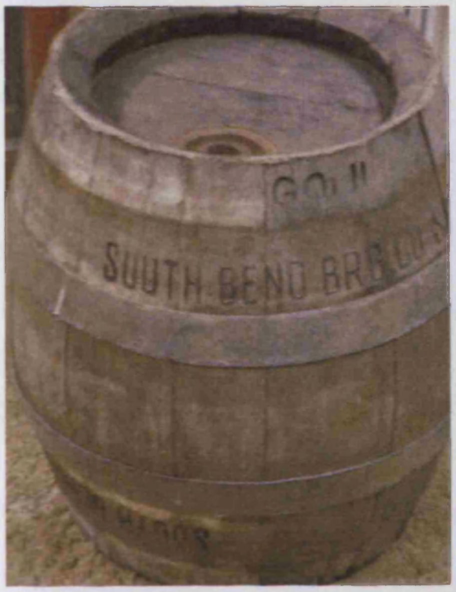


Fig 3.15 Beer barrel
www.coleauctionsinc.com

Gifford knew that Chartley did not brew their own beer but that they sent to Buxton for it once a week. Gifford had approached the French Embassy and had arranged for a mass of messages from France to be secretly passed to Mary by enclosing them in the bung used as a stopper in the beer.

CUT TO

THREE SC 18

Fig 3.16 Wooden barrel
www.trainstuffllc.com

When the beer arrived at Chartley, one of Mary's servants would remove the bung and take it to the her. The same method was used to send messages out from Chartley and the system worked really well, except for one flaw.

CUT TO

Three SC 19

Fig 3.17 Francis Walsingham
www.tudorplace.com.ar

The problem for Mary was quite simple; Gifford was a double agent. He was and had always been in the services of Walsingham.

CUT TO

THREE SC 20

WE SEE FRANCIS WALSINGHAM HOLDING A PARCHMENT LETTER, SEATED, TALKING TO THE UNSEEN INTERVIEWER

Verily I did find Master Gifford to be a fearless man. He was aware that his Catholic background would be of use to us and indeed it proved to be.
In this very letter that I have in my hand he did write,
' I have no scruples and no fear of danger. Whatever I am ordered to do I will accomplish.' He did write this letter to me in the year of Our Lord 1585.

CUT TO

THREE SC 21

Unknown to Mary a group of men had decided they would rescue her and help her to take the throne in place of Elizabeth.

Fig 3.18 Elizabethan accessories
www.heatherspages.net
CUT TO

THREE SC 22

The leader of the plot was a young man of 24 called Anthony Babington. He was handsome and had a reputation around the city as a charming and witty person. But he was also what today we would term a terrorist and the plot he was hatching would become known as the Babington plot.

Fig 3.19 Anthony Babington
www.lawbuzz.com
CUT TO

THREE SC 23

Fig 3.20 Ruins of Wingfield Manor, Peak District, England. Location where Babington plotted to free Mary Queen of Scots
www.timetravel-britain.com
CUT TO

Secretly, Babington held a deep resentment for the establishment. He believed the Protestant establishment had oppressed him and his family because of his faith. Priests were being accused of treason and the mass had been officially banned and those that remained loyal to Rome were taxed at exorbitant rates. As well as this, Babington's resentment was made worse by the death of Lord Darcy, his great-grandfather, who was executed for his part in an uprising against Henry VIII.

THREE SC 24

Fig 3.21 Tavern scene
www.gallery.euroweb.hu
CUT TO

Babington collected together a team of six other men and they met for the first time on one evening in March 1586. The conspirators agreed that the Babington Plot, as it was to become known, had to have the agreement of Mary, if it were to continue. This gave Walsingham the opportunity he needed.

THREE SC 25

Fig 3.22 Letter signed by Mary Queen of Scots
www.sheffieldmarkets.co.uk

Gifford delivered a letter to Babington from Mary

CUT TO

THREE SC 26

WE SEE BABINGTON READING THE LETTER; THE VOICE OVER IS READ BY MARY.

My supporters in Paris have made us aware of you and your work. It is most advantageous that we should hear from you and we look forward to doing so

CUT TO

THREE SC 27

Babington was persuaded to write to Mary

WE HEAR BABINGTON'S VOICE READING THE LETTER

Madam, myself with ten gentlemen and a hundred of our followers will undertake the delivery of your Royal person from the hands of your enemies. For the dispatch of the usurper, from the obedience of whom we are by excommunication of her made free, there are six noblemen, all my private friends, who for the zeal they bear for the Catholic cause and your Majesty's service will undertake that tragical execution.

CUT TO

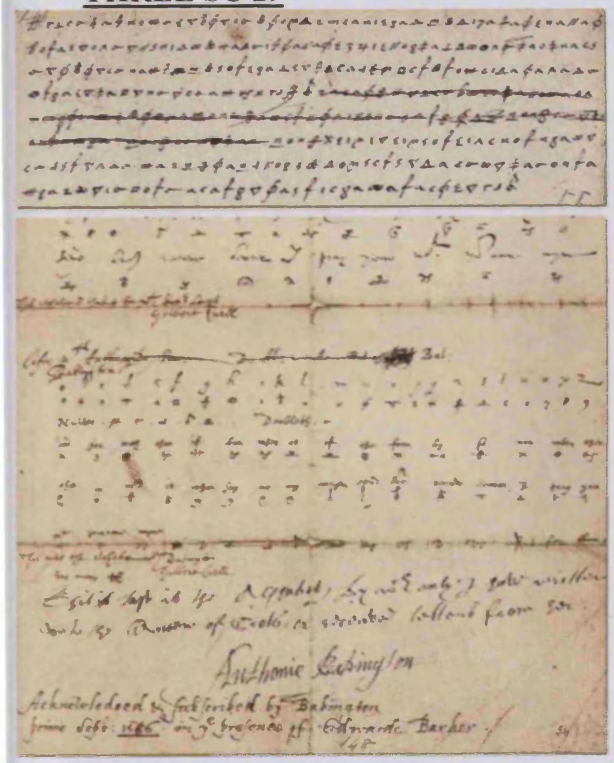
THREE SC 28

Gifford again used the technique of placing the message in the bung of the regular beer barrel, to get it past Mary's guards.

Fig 3.23 Beer-barrel ...
www.gutenberg.org

CUT TO

THREE SC 29



Babington was not a total fool. Here is the letter he wrote to Mary. He wrote it in cipher, so that even if the letter was intercepted it could not be understood; he was wrong.

Fig 3.24 Message used in the Babington Plot.
www.en.wikipedia.org

CUT TO

THREE SC 30

Fig 3.25 Sir Francis Walsingham
www.pbs.org

Walsingham had been aware of the state of ciphers and codes for some time and had set up a cipher school in London. In his employ was one Thomas Phelippes, a linguist and one of Europe's top cryptanalysts.

CUT TO

THREE SC 31

Fig 3.26 English Alphabet
www.roslin.com

Phelippes saw all messages to and from Mary and was consumed with zeal in cracking the cipher. He did this by calculating the frequency of each character in the message and matching these symbols with known symbols from the English alphabet. For instance, it is well known that the most frequently occurring letter in the English alphabet is the letter e. Phelippes could then attempt to match the most frequently occurring symbol to e.

CUT TO

THREE SC 32

Fig 3.27 Francis Walsingham
www.tudorplace.com.ar

When his decipherment found something that was absurd, he would simply start again, trying other substitutions. Eventually, when the framework of the message had been deciphered, the rest could be guessed from the context.

CUT TO

THREE SC 33

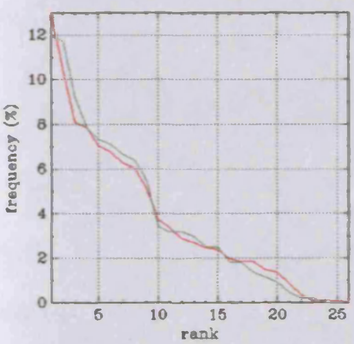


Fig 3.28 Playing spy with easy codes
www.eleves.ens.fr

When Babington's message was cracked and the proposed assassination of Elizabeth was evident, Phelippes made this information available to his master, Walsingham.

CUT TO

<u>THREE SC 34</u>

Fig 3.29 The actor Geoffrey Rush as Sir Francis Walsingham
www.aboutjamesfrain.com

WALSINGHAM
Master Phelippes you have done well. The court will look favourably on you.
PHELIPPES SMILES AND BOWS TO SHOW DEFERENCE
WALSINGHAM.
Mark you well Phelippes, not a word to anyone else or,
WALSINGHAM DRAWS HIS HAND ACROSS HIS OWN THROAT TO INDICATE THE POSSIBILITY OF PHELIPPES HAVING HIS THROAT CUT.

<u>CUT TO</u>

<u>THREE SC 35</u>

This was the point where Walsingham could have ordered the execution of Babington and his conspirators, but he wanted more than that.

Fig 3.27 Francis Walsingham.
www.tudorplace.com.ar
<u>CUT TO</u>

THREE SC 36

WE SEE WALSINGHAM SEATED AND SPEAKING TO THE UNSEEN INTERVIEWER

I was most concerned over the safety of our sovereign Queen and thus did my duty in her honour. 'Twas therefore a requirement to ensure that her Gracious Majesty was spared any attempts on her life in the manner that was suggested by the rebel Babington and involved the Queen of Scots. But there was a difficulty that perforce I was forced to overcome. At this stage I had no knowledge of the names of those involved, other than Babington and the Queen of Scots. I did request of Master Phelippes, who, as well as being blessed in the manner of codes and ciphers, can also write in any hand of any man or woman in England, to forge a letter.
I have it here and will read it to you.

' I would be glad to know the names and qualities of the six gentlemen who are to accomplish the designment; for it may be I shall be able, upon knowledge of the parties, to give you some further advice of the necessity to be followed therein, as also from time.......

WALSINGHAM VOICE FADES OUT.

CUT TO

THREE SC 37

WE SEE BABINGTON CONTINUING TO READ THE LETTER SUPPOSEDLY FROM MARY AND HEAR HIS VOICE FADE IN TO CONTINUE FROM WALSINGHAM IN THE LAST SCENE.

.... particularly how you proceed: and as soon as you may for the same purpose, who be already and how far everyone is privy herunto'.

CUT TO

THREE SC 38

WE SEE WALSINGHAM STILL SEATED AND TALKING TO THE UNSEEN INTERVIEWER.
And this he did and quite admirably, I must say. For when Babington received the letter from Phelippes, he did respond forthwith in a manner and fashion that did suggest his every faith in the cipher of his choosing. How wrong he was.

CUT TO

THREE SC 39

At this stage Babington needed to go abroad to organise an invasion and in order to go abroad he needed a passport from the office of none other than Francis Walsingham.

Fig 3.30 Sir Francis Walsingham
www.guildofstgeorge.com

CUT TO

THREE SC 40

WE SEE A MAN SITTING TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN, IT SAYS JOHN SCUDAMORE, OFFICIAL FROM WALSINGHAM'S OFFICE.

It was a most surprising occasion, I must say, to find the most treacherous and zealous man in England stood in my office and I simply did not have access to the required means of apprehension.

I did resolve to use zeal to trap this man Babington. In order to forestall his departure I did invite to celebrate his imminent departure with a trip to a local tavern. Whereupon I did entertain him with lavish tales, some which were the invention of my own mind and others that had a semblance of truth. It was then that I received a written confirmation that soldiers were destined to join us imminently with the express purpose of arresting Babington. He doth appear to have caught sight of the note or at least his caution was aroused and leaving his sword and coat, he made haste, saying he was to pay the tavern owner for our ale, but this was trickery on his part for he did secret himself from the tavern and was gone before our soldiers could arrest him.

CUT TO

THREE SC 41

Fig 3.31 Courthouse & hangman's scaffold
www.tropicalvegas.com

CUT TO

He did get away and was on the run for ten days. He was eventually captured in Harrow, where he had cut his hair and stained his skin to try and avoid capture. He was executed in the most torturous and disgusting way; in fact, it would be truer to say that all of the plotters were butchered to death.

THREE SC 42

Fig 3.32 1895 film of the execution of Mary Queen of Scots made by Alfred Clark of the Edison Kinestoscope Company believed to be the first movie special effect.
The execution of Mary Queen of Scots.
www.pbs.org

CUT TO

It was the 8th of February 1587 when Mary kept her appointment with the executioner.

THREE SC 43

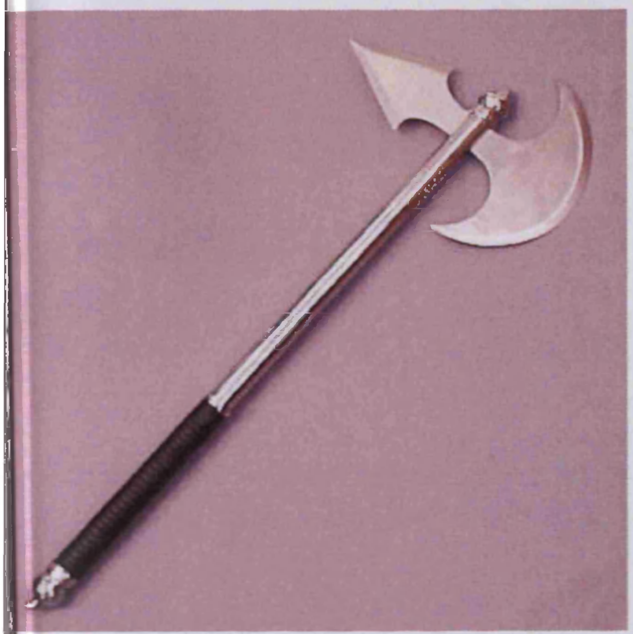


Fig 3.33 Medieval Executioner's Axe
www.rickssswords.com

Both Mary and Babington made the mistake of thinking their cipher was safe and they paid with their lives.

CUT TO

THREE SC 44

Fig 3.34 NATO
www.global-defence.com

Codes are an immensely powerful mathematical tool but they didn't really come into their own until the twentieth century. Two groups showed great interest in using codes: modern business, and the military.

CUT TO

THREE SC 45

But before the twentieth century, there were two inventions that led to the coming of age of cryptography. The first happened in 1884, when Samuel Morse invented the telegraphic code known as Morse code.

Fig 3.35 Samuel Morse
www.biografieonline.it
CUT TO

THREE SC 46

The second was the development and widespread use of the telegraph.

Fig 3.36 Telegraph pole
www.abc.net.au
CUT TO

THREE SC 47

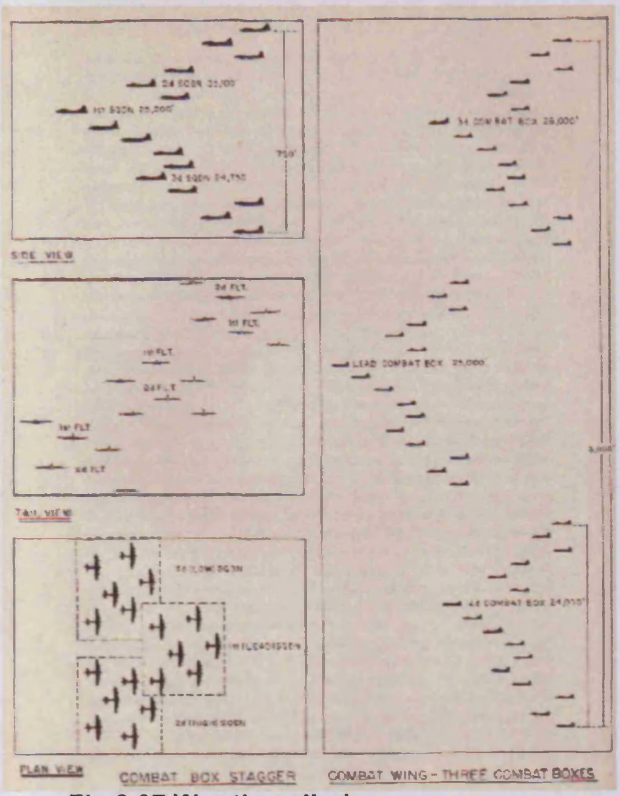


Fig 3.37 War-time diaries
www.fas-history.rutgers.edu

CUT TO

In wartime, telegraphy meant that it was possible to send messages some distance to the forward troops. Enemy agents soon found that they could simply tap into the line so it really was necessary to use codes and ciphers to protect the secrecy of the message.

THREE SC 48

Fig 3.38 Wireless telegraphy
www.spartacus.schoolnet.co.uk

CUT TO

But it was the invention of wireless telegraphy that freed the armies. Up to now telegraphy was only useful for a land-based static war. Wireless telegraphy or sound over a long distance without wires meant that contact was possible with ships out at sea and it was possible for two-way communication.

THREE SC 49

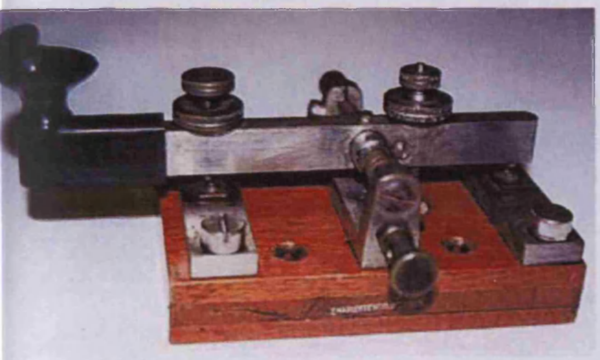


Fig 3.39 4270 Early German Luftwaffe Wireless
www.w1tp.com
CUT TO

There was, however, a disadvantage with two-way communication like this. All the enemy had to do was have a receiving set of its own and it could listen in to all of our transmissions. But the advantages outweighed the disadvantages. The only way forward was to assume that the enemy was listening and to make sure that your codes and ciphers were strong. This was a driving force in the development of ciphers, as it was more and more important to invest time and money in making them strong, and the Americans were not slow in seeing the need for a cipher machine.

THREE SC 50

Fig 3.40 The White House.
www.dblell.com
CUT TO

In 1915, an American called Edward Hebern, who was fascinated by cryptology, had devised a machine-generated code based on the electric typewriter that in 1915 was a very new but simple machine and it was this simplicity that was so important.

THREE SC 51

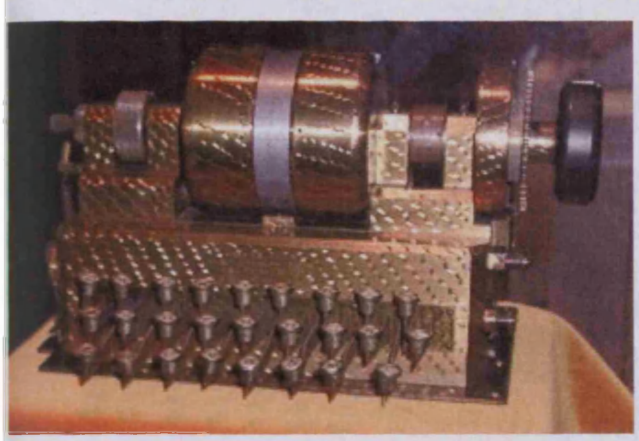


Fig 3.41 A single-rotor Hebern machine.
www.en.wikipedia.org

In reality, the letter keys on a typewriter are simply switches. When a letter C, for instance, was pressed, an electrical circuit was completed that led to the letter C being typed on the page.
What Hebern did was to simply rearrange the wiring, so that when the operator pressed a, then another letter, say K, was typed. The beauty of this development is that the script is enciphered as it is typed. But at the other end it could be retyped into a machine and the correct message would come out. The key to the success of this machine was a rotor. Each machine was full of rotors and each of these rotors had 26 contacts on each side, one for each letter of the alphabet. It was the internal wiring that formed the enciphering. As keys were typed, the rotors moved and a replacement letter was typed. So say an A had been pressed, it might type an F. But if the A were pressed again, the rotor would advance one letter to perhaps Y. So one rotor could produce 26 different alphabets. Hebern had five rotors on his machine. This meant that when rotor one had completed one revolution, rotor two moved forward one letter. When rotor two had completed one revolution, rotor three moved forward one and so on. This gave Hebern's machine eleven million eight hundred and eighty one thousand, three hundreds and seventy six different alphabets. But Hebern's machine was not the only one of its type.

CUT TO

THREE SC 52

Fig 3.42 Oosteinde Delft watercolour
www.enidlawsongallery.co.uk

Here in Delft in the Netherlands, in 1919 a patent was taken out by a Jugo Koch, for a cipher machine that he called the 'geheimschrifemachine'. It was a secret-writing machine. There is no evidence that he actually made the machine but a German engineer called Arthur Scherbius bought the patent right to the machine. He actually built a version of the machine but changed its name; he called his machine, Enigma.

CUT TO

THREE SC 53

Fig 3.43 Enigma machine stolen from Bletchley Park in 2000
www.frode.home.cern.ch

Scherbius' machine was similar to Hebern's, although they do appear to have been arrived at independently. But his machine had three rotors rather then the five Hebern had. But, and this was significant, the third drum reflected the current back through the other two, making it the equivalent of six rotors. There was a cost to this. It meant that it was never possible to encode a letter as itself. An A in the original message could never be encoded as an A in the final message. This seems innocent enough, frankly a minor defect, but it was to be a serious weakness.

CUT TO

THREE SC 54

Scherbius was in production by 1923 making his Enigma machine in his Berlin workshop and it was on public exhibition at the Leipzig Trade Fair and at the International Postal Union Congress
It was promoted as a cheap and reliable way of encoding telegrams used for commercial purposes and the Scherbius was rightly proud of it.

Fig 3.44 One of the first Trade Fairs
www.angabisuteria.com

CUT TO

THREE SC 55

The German Post Office even publicly demonstrated the power of Enigma by sending a coded greeting wire to the Congress and decoding it for all to see.

Fig 3.45 German Post Office
www.hh.schule.de

CUT TO

THREE SC 56

Fig 3.46 Sturmabteilung SA Brownshirts
www.members.aol.com
CUT TO

But these were troubled times in Germany and the rise of Nazism was underway. So it wasn't long before the Enigma machine had come to the notice of the cipher department, an important part of the small army permitted to the Germans under the treaty of Versailles.

THREE SC 57

Fig 3.47 Erich Fellgiebel
www.swr.de
CUT TO

The head of this unit was a man called Colonel Erich Fellgiebel, a highly experienced field signal officer who was destined to rise to the rank of Major General and to command all of the German Armed Forces Signals. The result of his examination was that the machine was quietly withdrawn from public scrutiny and the commercial market and was improved for the nascent Wehrmacht.

THREE SC 58

This is the machine that was issued to the German Armed Forces. It started off with three rotors and a plug board that could make a super encipher.

Fig 3.48 Cipher Machines: The German Enigma
www.w1tp.com

CUT TO

THREE SC 59

WE SEE ERICH FELLGEIBEL TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN IT SAYS ERICH FELLGEIBEL

We determined that the messages sent would be completely indecipherable without an Enigma machine and even with a captured Enigma, whilst it may be theoretically possible, few men possess that ability.

CUT TO

THREE SC 60

Fig 3.49 Poland Map
www.travel.yahoo.com
CUT TO

Few may have possessed the knowledge but many were interested in what the Germans were doing. One country with a vested interest in knowing what was going on was Poland. At this time Poland was surrounded by enemies and had developed an extremely efficient and professional intelligence service, one that was highly regarded around the world by fellow professionals.

THREE SC 61

Fig 3.50 Poland, coat of arms
www.civicheraldry.com
CUT TO

The Poles had become extremely adept at breaking ciphers and codes, but all of this changed in 1928. They found a code they could not break. They assumed it was mechanically constructed; they were right, it was. But then by sheer chance, the Poles had a lucky break.

THREE SC 62

Fig 3.51 German soldiers using an Enigma machine during the Second World War
http://plus.maths.org/issue34/features/ellis/

Sometime in January 1929 late on a Saturday afternoon, A German Official from the German Legation in Warsaw was making urgent enquiries at the Railway Parcels Custom Office regarding a packing case that had come from the Foreign Office in Berlin. He demanded it be cleared immediately. This set the alarm bells ringing for the Poles who correctly began to suspect that Berlin had made a serious error. Something that should have been sent through the Diplomatic Bag had been sent ordinary freight and the Poles were anxious to know what it was. They told the man it had yet to arrive and would not do so since the office was due to close for the weekend. The excise men then contacted Polish Military Intelligence.

CUT TO

THREE SC 63

Fig 3.52 Crate
www.indygear.com

The Poles were right to be suspicious. In the crate packed neatly in straw was a brand new Enigma. Over that weekend intelligence experts carefully examined the machine before repacking it for collection on Monday morning.

CUT TO

THREE SC 64

Fig 3.53 Enigma-rotors
www.ilord.com

This gave the Poles vital information, most notably the internal wiring of the machine, the method of operation and its detailed mechanical construction. What was clear was that the military enigma was an advance on the previous civil machine and that had implications for the Poles. To keep pace with it, they would need top analysts well schooled in advanced techniques of higher mathematics, so that is exactly what they did.

CUT TO

THREE SC 65

WE SEE A YOUNG MAN SEATED TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN IT SAYS JERRY ROZYCKI, MATHEMATICIAN.

I was one of the three recruited from Poznan University. Marian Rejewski was another and he was sent to Gottingen University to learn some very high-powered mathematics. Henry Zygalski was the third member of the team and he was a valuable asset.

CUT TO

THREE SC 65

They went through four years of training and by 1932 they could crack the Enigma codes in just a few months. This was a remarkable achievement.

Fig 3.54 The gate in the University of Göttingen.
www.princeton.edu
CUT TO

THREE SC 66

The Poles did manage to acquire a commercial Enigma and upgrade it to military levels, but then they had another piece of good luck.

Fig 3.55 Cipher machines: the German Enigma
www.w1tp.com
CUT TO

THREE SC 67

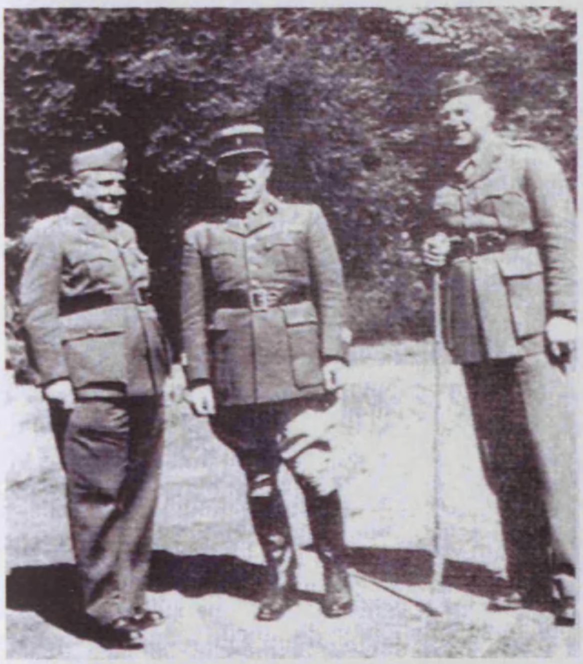


Fig 3.56 Gustave Bertrand
www.militarni.pl

Early in 1931 a lowly paid clerk from the German Ministry of Defence made contact with the French Secret Service. He said his name was Sclmidt but we do not know if this was genuine or not. He was code named Ash and he promised much, but he was not generally highly regarded by the French, but there was one man, though, who found him interesting, Captain Gustave Bertrand, the then Head of the French Cryptography Bureau. He was very interested indeed and for a simple reason: Ash had a brother and that was very exciting.

CUT TO

THREE SC 68

WE SEE A MAN TALKING TO THE UNSEEN INTERVIEWER.
ON THE SCREEN IT SAYS CAPTAIN GUSTAVE BERTRAND

As Head of the Bureau I was intrigued by what Ash had to offer us. Many of my colleagues felt it was not important but when we found that Ash had a brother who was higher up in the German Army Command and who, according to Ash, was willing to supply secret documents. I felt this was money well spent and I know our Polish colleagues felt the same.

CUT TO

THREE SC 69

In 1932 an exchange took place, which the Poles and French regarded as priceless. Ash passed over a copy of the German Army Instruction Manual for the Enigma machine. This was a codebook giving the keys to Enigma and a sample message that had been enciphered and deciphered.

Fig 3.57 An Enigma codebook recovered from the captured U-505
www.answers.com
CUT TO

THREE SC 70

This made life a lot easier for the code breakers and obviously meant they could read everything the Germans were sending and receiving.

Fig 3.51 German soldiers using an Enigma machine during the Second World War
http://plus.maths.org/issue34/features/ellis/
CUT TO

THREE SC 71

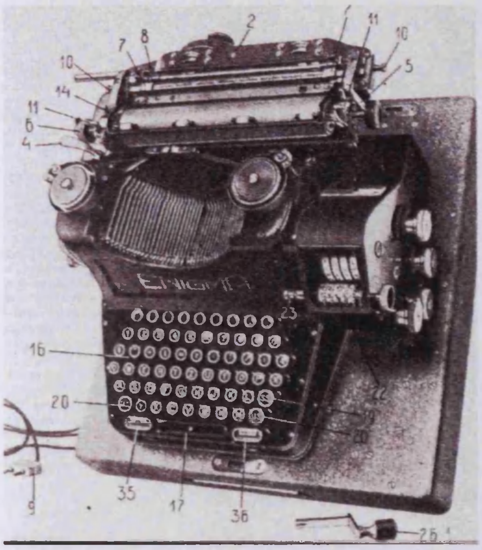


Fig 3.58 An early Enigma model B
www.armyradio.com
CUT TO

The imminent war in Europe caused the Poles to reassess their knowledge of the use of Enigma. They knew it was going to be vital in the war, so they analysed the political situation and made a judgement.

THREE SC 72

Fig 3.59 Hitler
www.what-means.com
CUT TO

The Germans had withdrawn from a pact with Poland and Hitler was become more aggressive with his rhetoric towards Poland. The Poles therefore decided to approach the UK and France. They invited the British and French to a meeting to show them what had been discovered, to show them Enigma.

THREE SC 73

Fig 3.6 Marian Rejewski
www.answers.com
CUT TO

Different sources give different dates for when the meeting took place but the fact is it did take place initially on either January 9 or January 10 in 1939. What took place at the meeting is unknown but the outcome must have been favourable because a further meeting was arranged for 24 July 1939.
The second meeting took place, this time in Poland. The host included at least two Senior Polish Officers and one or two analysts, including Marian Rejewski. The French delegation included Captain Bertrand and an analyst called Captain Braquerie. The British delegation has been under doubt for some years. There certainly was a Commader Denniston and Dilwyn Knox and there was the famous Professor Sandwich. The identity of Sandwich has been a mystery for years and various suggestions have been made, including the famous Alan Turing, the well-known mathematician. In fact, Professor Sandwich was a government diplomat called Humphrey Sandwith, the head of the Interception Unit at the Admiralty, and his lack of knowledge of mathematics at this level was therefore understandable.

THREE SC 74

Fig 3.62 Invasion of Poland Sept 1939
www.cla.calpoly.edu
CUT TO

The penetration that the Poles made into Enigma astounded both the French and the British. They were about ten years ahead of anyone else in the world. There was to be one more surprise. The Poles offered both the British and the French two spare replicas of the Enigma machine. The British machine was delivered to London on August 16, 1939. Sixteen days later, the Second World War began.

THREE SC 75

Fig 3.62 Bletchley Park
www.smithstuff.net

And this is how we come to the now famous Bletchley Park near Milton Keynes. It is now well known that this was the location of the code-breakers because it was here that the government of the day set up the Code and Cipher School. And it was here that they devised strategies to break Enigma.

CUT TO

THREE SC 76

WE SEE A MAN SEATED TALKING TO THE UNSEEN INTERVIEWER. ON THE SCREEN IT SAYS COMMANDER ALISTAIR DENNISTON, HEAD OF BLETCHLEY.

I was responsible for the recruitment of the mathematicians and I was fortunate enough to get the likes of Gordon Welchman and Alan Turing. Turing had already made a name for himself in 1936 by writing a seminal paper on computable numbers. He had the vision to recognise that machines could be harnessed to take away much of the drudgery carried out by people.

CUT TO

THREE SC 77

Turing was a genius; he was certainly a man before his time. He had vision and he had ability and he used it during the war where he was responsible for many of the insights in cracking Enigma. He was later to commit suicide and is regarded by many as one of the greatest losses to mathematics.

Fig 3.63 Alan Turing
www.fusionanomaly.net
CUT TO

THREE SC 78

Fig 3.64 The Enigma
www.25.brinkster.com
CUT TO

So how much of a threat was the Enigma? Just to put this into perspective: there were about 200 000 Enigma machines in use during World War 2 and there were different versions of the machine. The Army and the Luftwaffe had a machine with 10^{21}, that is 1000 000 000 000 000 000 000 settings. But the Navy machine had 10^{23} settings, in other words even more combinations. These were the number of possible combinations of codes, the number of possible outcomes that had to be broken. To crack this machine would be truly remarkable but that is exactly what they did.

THREE SC 79

The codes they broke at Bletchley told their own grim story. The Military intelligence obtained from cracking the codes helped to save the 340 000 men who were evacuated from Dunkirk between May 27 and June 6 1940. This was a major defeat for the forces but it was a major victory for the code breakers.

Fig 3.65 June 3, 1940 - Evacuation of Dunkirk
www.historyplace.com

CUT TO

THREE SC 80

Fig 3.66 Huts 3 and 6 at Bletchley Park
www.faculty.goucher.edu

CUT TO

The code-breaking activities took place in these huts. Hut 6, for instance, had special responsibility for attacking the German Army's Enigma communications. It then passed its decrypts on to Hut 3 where the messages were translated and attempts made to exploit the information. Hut 8 had special responsibility for the Naval Enigma and passed on their decrypts to Hut 4. As the war went on, the importance of the work at Bletchley grew. At the start of the war there were two hundred people at Bletchely. By the end of the war, it would grow to 7000.
So how did they start tackling Enigma?

THREE SC 81

Fig 3.67 Bletchley staff
www.qsl.net
CUT TO

During the autumn of 1939, the staff at Bletchley spent their time learning the intricacies of the Enigma machine and its cipher ability. They had more staff than the Poles but they still had to work hard to master the Polish techniques. So the code breakers were capable of coping with a greater number of scramblers, but they also had to deal with the fact that the Enigma had been developed by the Germans from the earlier machine seen by the Poles and was far harder to break, about ten times harder. Added to this was another difficulty. Every day the German Operator would move to a new day key. This meant that regardless of where the code breakers had got that day, when the day key changed they had to start from scratch all over again. This often took several hours but as soon as they discovered the settings for that day, accumulated traffic could be read and invaluable information secured for the war effort.

THREE SC 82

Fig 3.68 10 May 1940 33 Allied aircraft attack German positions
www.raf.mod.uk/bombercommand
CUT TO

When work got particularly tough for the code-breakers, they were not averse to pulling strings with the RAF. When a particular code for the day was impenetrable, the code breakers had an ace up their sleeve; at these times the RAF was scrambled to attack a position off the French Coast. This led to an increase in traffic from the Germans reporting back that they had been attacked. This traffic was then analysed by the code breakers and often yielded clues that helped crack the code for that day.

THREE SC 83

Fig 3.69 German troops march toward the Arc de Triomphe.
www.ucc.uconn.edu
CUT TO

The power of breaking the codes was obvious. If the German code was broken, then all of their plans were transparent. News of an imminent attack meant that the Allies could meet it with re-enforcements. For instance, Bletchley, who provided the armed forces with a detailed picture, cracked the German invasion of Denmark and Norway in 1941. In the same way, during the Battle of Britain advanced warning of bombing raids could be given.

THREE SC 84

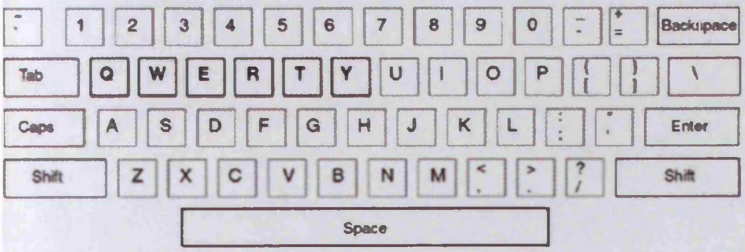


Fig 3.7 QWERTY Keypad
www.dca.ca.gov
CUT TO

After they had mastered the Polish techniques, the code breakers had to come up with some of their own. After all, the machine was now ten times harder. One of the things they did was to latch onto obvious message keys. Each message was supposed to start with a new message key but the realities of the heat of battle meant that the German forces very often used obvious keys like three letter combinations that followed each other on a keypad, say BNM or GHJ. These keys became known as cillies. Another cillie was the repeated use of a girlfriend or wife's name or initials of their name. This was a good starting point to crack the code; it meant that the hard way could often be avoided.

THREE SC 85

Cillies were not a weakness in the Enigma machine, but a weakness in the way the machine was used. At a higher level human error also compromised the security of the machine. Those responsible for the compilation of the codebooks had to decide which of the scramblers would be used each day and the order in which they would be used.

So, for instance, if the scramblers were labelled 1,2,3,4 and 5, if 1,2 and 5 were picked on the first day, on the second day it would be possible to have 3,1,4 on the second day but not 3,1,5 because 5 would be in the same position as it had been on the previous day.

Fig 3.71 German Enigma machine
www.home.comcast.net
CUT TO

THREE SC 86

The code-breakers at Bletchley soon realised what happened and this was an absolute god-send for them because it meant there were many combinations that they could ignore. This dramatically cut their workload because once the scrambler arrangement for that day had been identified, they could immediately rule out half of the scrambler arrangements for the next day. The effect was to reduce their workload by half.

Fig 3.72 Bletchley Park
www.unimelb.ieeevic.org
CUT TO

THREE SC 87

There was also a rule that the plug board could not include a swap between any letter and its immediate neighbour. So, for instance, *n* could never be swapped with *m* or *o*. This again had the effect of reducing the number of available keys.

Fig 3.73 The Enigma plug board
www.nku.edu

CUT TO

THREE SC 88

This searching for new shortcuts was necessary for the whole war because the Germans did keep evolving the Enigma machine. One of the reasons they were successful at Bletchley was because of the nature of the team. They had a mix of scientists, mathematicians, linguists, classicists, and chess masters as well as crossword experts who would pass the problem around the hut.

Fig 3.74 The German Enigma
www.w1tp.com

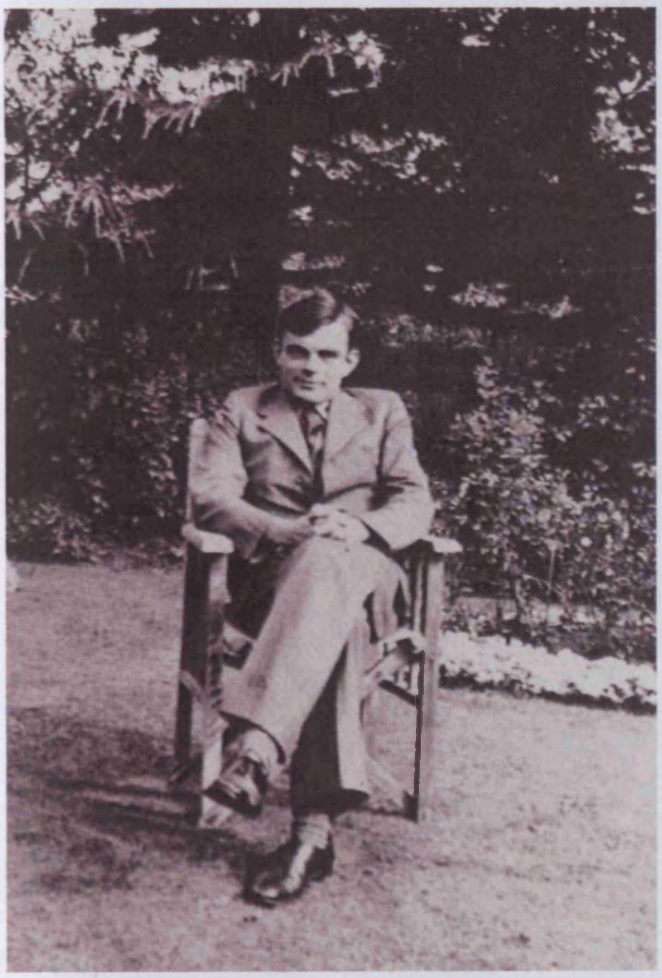
CUT TO

THREE SC 89

WE SEE A MAN TALKING TO THE UNSEEN INTERVIEWER.
ON THE SCREEN IT SAYS ALAN TURING
ALAN TURING (HESITATINGLY).
It was a matter of finding the right mental tools to do the job. Often, if we could only find someone in the hut who could crack a chink in the code, then that would open a door and we could get in and crack the code, but it really was very difficult. I did find a way of getting a crib based on the weather forecast. We found that the Germans sent a weather forecast every morning at about 6am. It made sense to find the German word for weather in this; this was a possible opening for us.

CUT TO

THREE SC 90

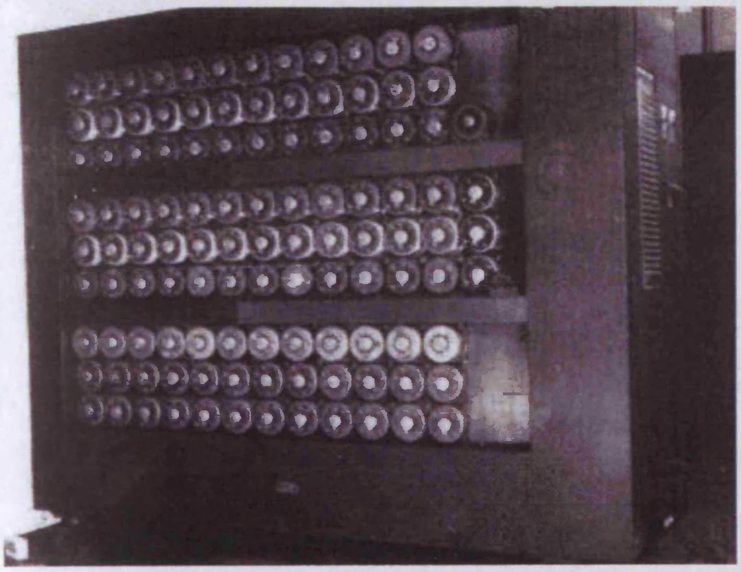


A crib was the name given to a combination of a piece of plain text and a piece of ciphertext. Turing seemed confident that if he could exploit the cribs, he could crack Enigma. Say he found that rtpptg stood for wetter, then it might be thought that a cryptanalyst should type in rtpptg into an Enigma machine and see what came out. If he didn't get it first time, he could try again and again.
The problem here was that there are 159 million, million, million possible settings and they would all need to be checked.

Fig 3.75 Alan Turing in the Garden
www.f.home.cern.ch

CUT TO

THREE SC 91

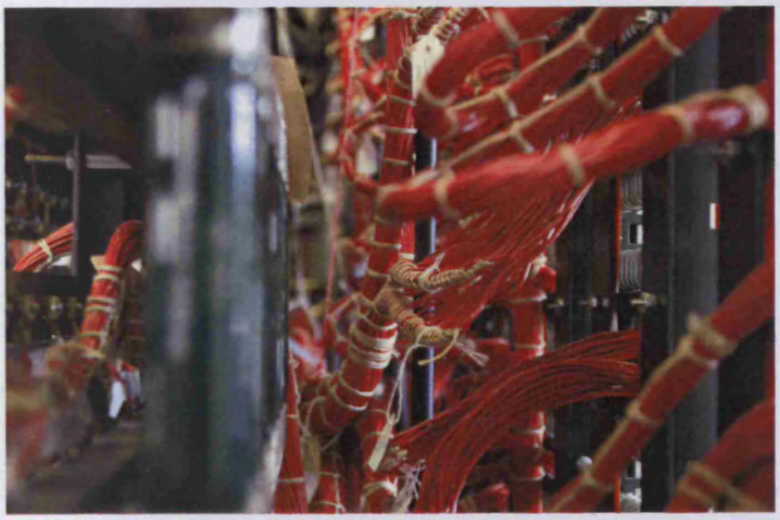


It was Turing alone who had the necessary background in mathematical machines, and by applying this background knowledge he managed to simplify the arrangements of a mental model of Enigma. From this set of mental musing, Turing was able to develop a machine to compute all of the different combinations of codes and find an answer. It was similar to the machines created by the Poles before the war and was called a Turing Bombe.

Fig 3.76 The Turing Bombe
www.ellsbury.com

CUT TO

THREE SC 92



Turing's bombe arrived on March 14, 1940, and it was a grave disappointment. It was a box of about 2m tall, 2m long and 1m wide and they called it Victory. However, Victory was much slower than had been expected. It took up to a week to find a key to a code.

The Bletchley analysts immediately set to and created a modified design that was to take another four months to build.

In the meantime, the code-breakers had anticipated that things might get worse for the allied forces, and they were right.

Fig 3.77 Bombe wiring (A rebuild of Turing's bombe)
www.gallery.spacebar.org

CUT TO

THREE SC 93

Fig 3.78 Enigma
www.usaaf.net

On May the first 1940, the Germans changed the key code for Enigma. They no longer repeated the message key. This meant that cracking Enigma suddenly became a lot harder. Now there was an information blackout.

CUT TO

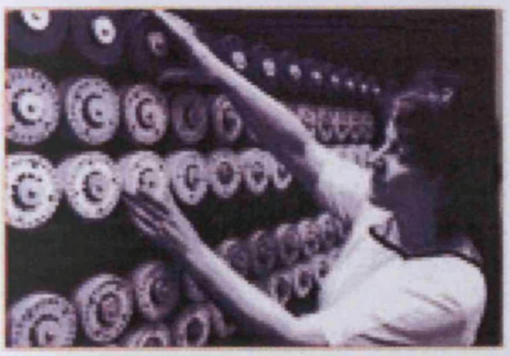
THREE SC 94

This meant that all shipping was again at a greater risk; the Allies could not crack the new code until August 8.

Fig 3.79 Battle of the Atlantic
www.ahoy.tk-jk.net

CUT TO

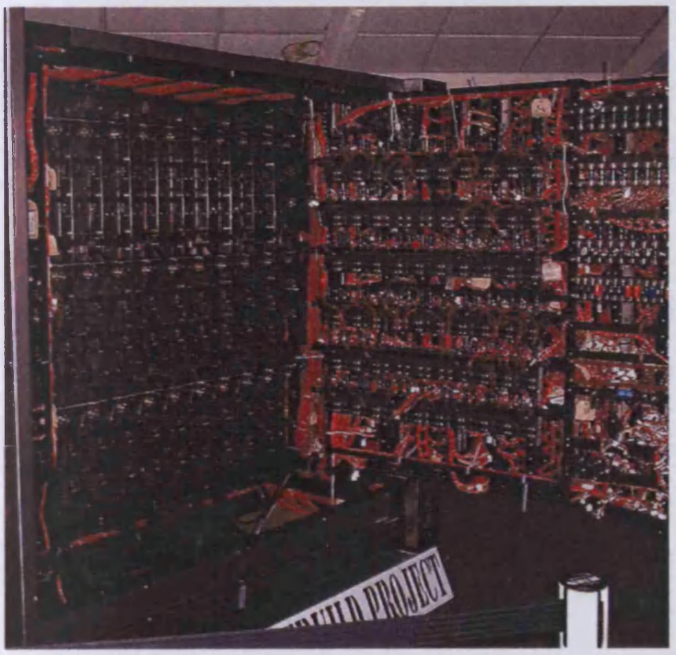
THREE SC 95



It was on August 8 that the new bombe arrived and it was this machine that fulfilled all of Turing's expectations.

Fig 3.8 A mock-up of Turing's Bombe
www.exaro.co.uk
CUT TO

THREE SC 96



Within 18 months, the code breakers at Bletchely had 15 more bombes working away, tirelessly exploring scrambler settings, using cribs, and revealing keys. Each machine spent its time clattering away looking for matches between plain and cipher text.

Fig 3.81Turing's Bombe machines
www.compshopper.co.uk
CUT TO

THREE SC 97

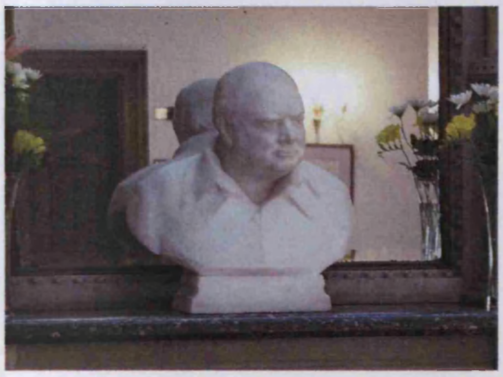


Fig 3.82 Bust of Churchill at Bletchley Park
www.erowell.co.uk

Only the most senior figures of the war cabinet were privy to the intelligence gathered at Bletchley. Churchill himself had visited the Park on Sept 6, 1941, and it was this visit that had led to a letter from Turing and some of the other code breakers.
Bletchley had a new director at this time, Commander Edward Travis, and whilst he had approved the new bombes, he blocked attempts to recruit more staff, believing that more staff could not be justified.

CUT TO

THREE SC 98

WE SEE TURING WITH THE OTHER MATHEMATICIANS. HE IS READING AND THE OTHERS ARE NODDING
V/O IS TURING'S VOICE
'Some weeks ago, you paid us the honour of a visit and we believe that you regard our work as important. You will have seen that, thanks largely to the energy and foresight by Commander Travis, we have been well supplied with the bombes for the breaking of the German Enigma Codes. We think, however, that you should know this work is being held up….'.

FADES OUT

THREE SC 99

WE SEE THE BACK OF A BLURRED VISION OF CHURCHILL WHO IS READING THE LETTER FROM TURING ET AL V/O **FADES IN AS CHURCHILL'S VOICE** 'And in some cases is not being done at all, principally because we cannot get sufficient staff to deal with it. Our reason for writing to you direct is that for months we have done everything we possibly can through the normal channels and that we despair of any improvement without your intervention.'

CUT TO

THREE SC 100

Yes, this was insubordination, but it had the right effect.

Fig 3.83 Turing
www.rom.gr

CUT TO

THREE SC 101

WE SEE CHURCHILL IN HIS STUDY. SHOT IS FROM THE BACK OF HIS HEAD AND IS SLIGHTLY OUT OF FOCUS. HE IS HOLDING A PIECE OF PAPER AND READING AS IF CHECKING IT. WE CAN SEE THE WORD *MEMORANDUM* AT THE TOP OF THE PAGE.
THE VOICE OVER IS CHURCHILL'S.
Make sure they have all they want on extreme priority and report to me that this has been done.

CUT TO

THREE SC 102

They got what they wanted. There were no more barriers. By the end of 1942 there were 42 bombes and they even built a new bombe station at Gayhurst Manor, just North of Bletchely.

Fig 3.84 Gayhurst Manor
www.mkheritage.co.uk

CUT TO

THREE SC 103

Fig 3.85 North Africa
www.fefcmissions.com
CUT TO

It is easy to treat Enigma as one vast telecommunications system but it was not this at all. In fact, there were several different networks. In North Africa the Germans had their own network and their codebooks were different from those used elsewhere like Europe. So when the experts at Bletchley cracked the European code for that day, this was no use whatsoever in North Africa.

THREE Sc 104

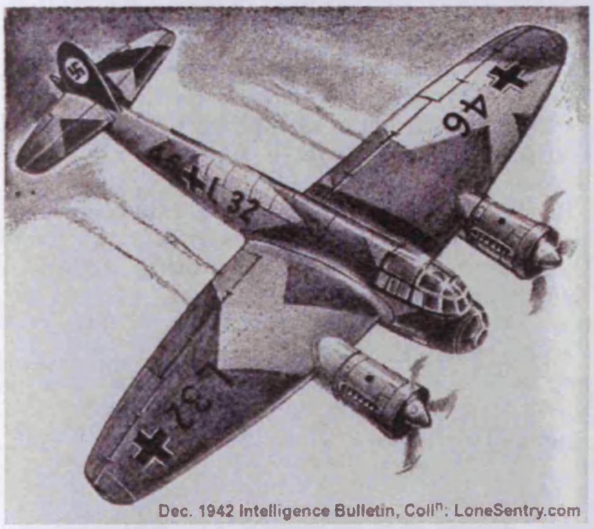


Fig 3.86 Junkers Ju88, German Luftwaffe
www.lonesentry.com
CUT TO

Similarly the Luftwaffe had their own network and so to decipher the Luftwaffe traffic, Bletchley would need to work out the day key. But it was the Kreigsmarine that was the hardest of all, simply because the German Navy operated a more sophisticated machine. The Naval version of the Enigma had eight scramblers rather than five. This meant that there were almost six times the number of scrambler arrangements and clearly almost as many as six times the number of keys that needed checking.

THREE SC 105

Fig 3.87 Ian Fleming
www.home.comcast.net

There were literally thousands of these machines in circulation amongst the German forces, so it was inevitable that some common use would occur. Phrases like ' To the Officer Commanding,' ' By order of the Fuhrer' and even ' Heil Hitler' would appear regularly and this was ideal meat and drink for the code-breakers since a decode in one cipher would provide a key to others. The other heaven - sent opportunity for the code-breakers was the key setting. It was easy for the German operators to become careless. If you remember, they had to have three letters for their call sign and these were to be changed every day. However, often orders were defied. It was easier to use the same letters, very often the letters of a man's wife or girlfriend's name. This was like leaving a door open and the code-breakers could soon get in.
But the easiest way forward was to capture a codebook without the Germans knowing and that was where James Bond creator Ian Fleming came into his own.

CUT TO

THREE SC 106

One strategy for cracking the Enigma code that was considered was to steal the keys. At that time Fleming was a member of Naval Intelligence and suggested crashing a captured German bomber into the channel close to a German ship. The Germans would then rescue their comrades who in reality would be British Officers in disguise. The British Officers would then board the ship and steal the codebooks.

Fig 3.88 Ian Fleming and Ornithologist James Bond
www.ajb007.co.uk

CUT TO

THREE SC 107

Fig 3.89 German ships
www.spartacus.schoolnet.co.uk
CUT TO

It was the German codebooks that contained the information that was needed to establish the encryption key. The fact that ships were away from base for extended period meant the codes would be good for at least a month. This was a huge opportunity for Bletchley to be able to decipher all codes for a month. The plan was called Operation Ruthless but because there was no German Shipping in the area, it was shelved indefinitely and was finally cancelled. But if they could just capture a codebook, it would make life so much easier for the codebreakers.

THREE SC 108

Fig 3.90 U110 German U-Boat with German naval rating using Enigma This was the machine captured by British Forces.
www.mikekemble.com
CUT TO

Despite what Hollywood would have us believe, the British captured the first Naval codebook.

THREE SC 109

Fig 3.91 HMS Bulldog H 91 seen here before World War II
www.uboat.net

In May 1941, the U-Boat U-110 was attacking a convoy along with U-201, when the captain, Fritz Julius Lemp, may have left his periscope up for too long. It was spotted by a British Corvette, HMS Aubretia. Aubretia first attacked together with HMS Bulldog and Broadway.

CUT TO

THREE SC 110

Fig 3.92 Lemp seen here on U-30, his previous command before U-110
www.mikekemble.com

Different historians give different accounts of what happened next. But the fact is that Aubretia dropped depth charges on U-110. The U -Boat survived the first attacks but when Bulldog and Broadway came into the fight, the U -Boat surfaced, according to some because Lemp thought the U-Boat was sinking and he wanted to save his men.

CUT TO

THREE SC 111

Accounts again differ here. Some say that when the U-Boat surfaced, Bulldog immediately went on a ramming course but the Captain of the Bulldog realised that a capture might be possible and tried to avoid hitting the U-Boat, which he almost did. Lemp gave the abandon ship order.

Fig 3.93 Boarding party heading for U-110 sub from HMS Bulldog
www.mikekemble.com

CUT TO

THREE SC 112

Again, according to some sources Lemp realised too late that the sub was not going to sink and tried swimming back to rescue the codebooks and the Enigma machine. A British sailor may have shot him, but either way he did not make it.

Fig 3.94 Kapitänleutnant Fritz-Julius Lemp after receiving his Knights Cross.
www.uboat.net

CUT TO

THREE SC 113

Lieutenant David Balme led a boarding party and the team managed to secure the Enigma machine, the rotors and the current cipher books, a huge prize for the British.

Fig 3.95 Lieutenant David Balme
www.news.bbc.co.uk
CUT TO

THREE SC 114

What happened next is again under debate. The U-Boat sank whilst under tow to Iceland but whether this was a deliberate act by the British is unclear. You see the German crew were unaware that Enigma had been captured and it was important that the German High command had no knowledge of the capture. If the Germans felt that the machine and codebooks had gone to the bottom of the Ocean, then they would feel that the codes were safe.

Fig 3.96 Map of Iceland
www.scantours.com
CUT TO

THREE SC 115

Fig 3.97 U-Boat attack just before bombs away. Shot from a Catalina.
www.navylib.com
CUT TO

When material had been secretly captured, it was important to keep the capture secret. An example of this was the tracking of U-Boats. U-Boats would cluster around a convoy before they attacked and therefore it was vital to know where they were. But to attack all U-Boats would have told the German authorities that the British had access to the codes for Enigma. So in cases like this, some U-Boats were allowed to escape and some were attacked often only after a spotter plane had been flown out over the area. This then legitimised the attack.

THREE SC 116

Fig 3.98 Kurt Fricke
Commander-in-Chief of the German Navy
www.feldgrau.com
CUT TO
THREE SC 117

But the Germans were not stupid. Admiral Kurt Fricke ordered an investigation into security when he became suspicious at British successes. He wanted an assessment of the likelihood of the British having broken the Enigma code. The report was clear: it was either natural misfortune or a British spy was managing to get information back to the British. The possibility that the British were reading the Enigma codes was so inconceivable that it was considered impossible.

Fig 3.99 Purple Japanese cipher machine
www.mccullagh.org
CUT TO

The Americans also had their major successes during the war. They managed to crack the Japanese machine cipher called Purple and it was in the US that Native Americans joined the war effort. But the Americans also had an unusual approach to code breaking.

THREE SC 118

Fig 3.100 Philip Johnston
www.signonsandiego.com
CUT TO

An engineer from Los Angeles, a man called Philip Johnston, came up with an ingenious idea of encrypting the language used to send ciphers. He suggested using Native Americans to translate the message into their language and then send it. The receiving end also had a Native American who could translate the message back to English. This they did and it worked.

THREE SC 119

Fig 3.101 The Navajo Indian Code-Breakers
www.nau.edu

It actually worked incredibly well, with members of the Navajo tribe taking on the role. They were a vital component in the armoury of the US. But like the UK code-breakers, their work was classified and it was not until 1968 that they were allowed to talk about it.

CUT TO

THREE SC 120

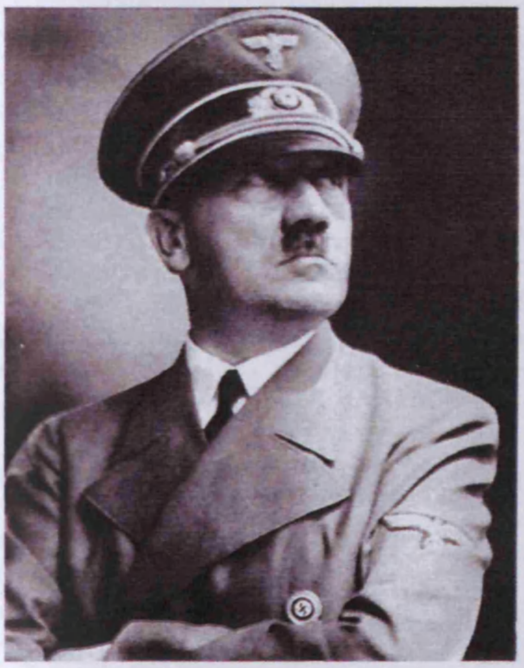


Fig 3.102 Hitler
www.upload.wikimedia.org

So was that it for code breaking? Well actually, no.
There was one more to break. It was the method used to communicate between Hitler himself and his generals and it was called Lorenz. This really was the big one.

CUT TO

THREE SC 121

Fig 3.103 Working at Bletchley
www.ilord.com
CUT TO

And so the attention turned to Bletchley again.

THREE SC 122

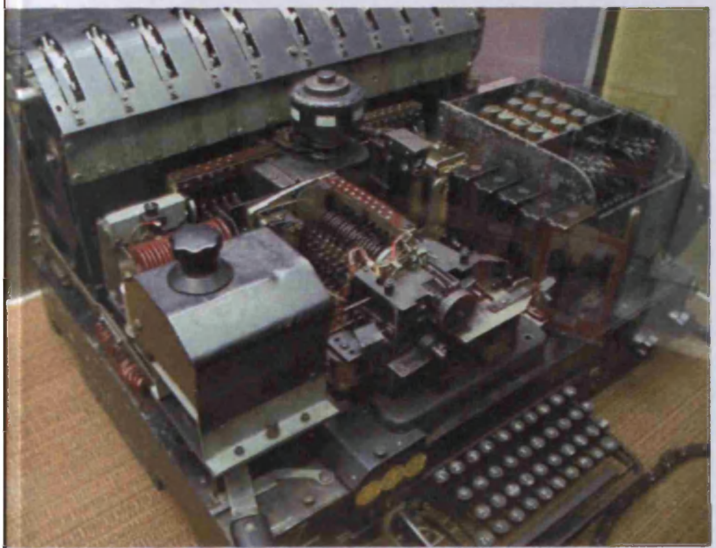


Fig 3.104 The Lorenz Cipher machine. It was the most advanced encryption machine the Germans made.
www.rubycon.org
CUT TO

Although the Poles had given a lead to developing code-breaking technology and Turing's bombes had certainly helped, the Lorenz cipher was far harder to crack.

THREE SC 123

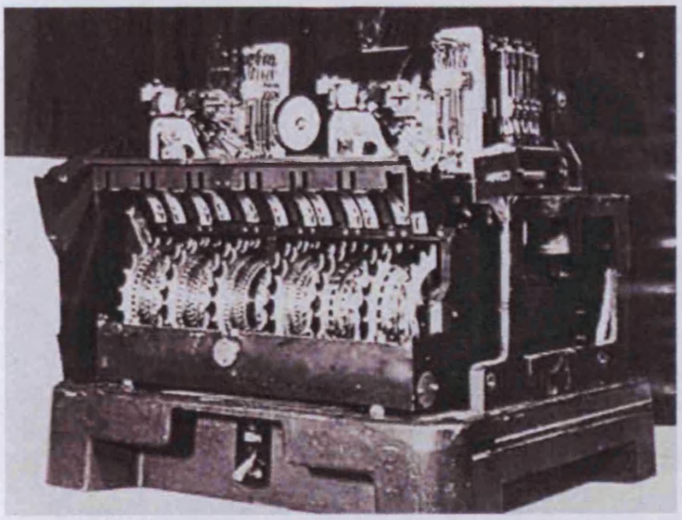


Fig 3.105 The Lorenz Machine
www.alanturing.net/.../ LorenzPhoto.html

The encryption on a Lorenz SZ40 machine was challenging. Although a Lorenz operated in a similar way to the Enigma, it was in fact far more complicated. In order to break the Lorenz cipher, they would have to engage in a mixture of matching, searching, using statistical analysis and make judgements on their work. But the Turing bombe simply was not up to the task of deciphering Lorenz ciphers-they needed something else.

THREE SC 124

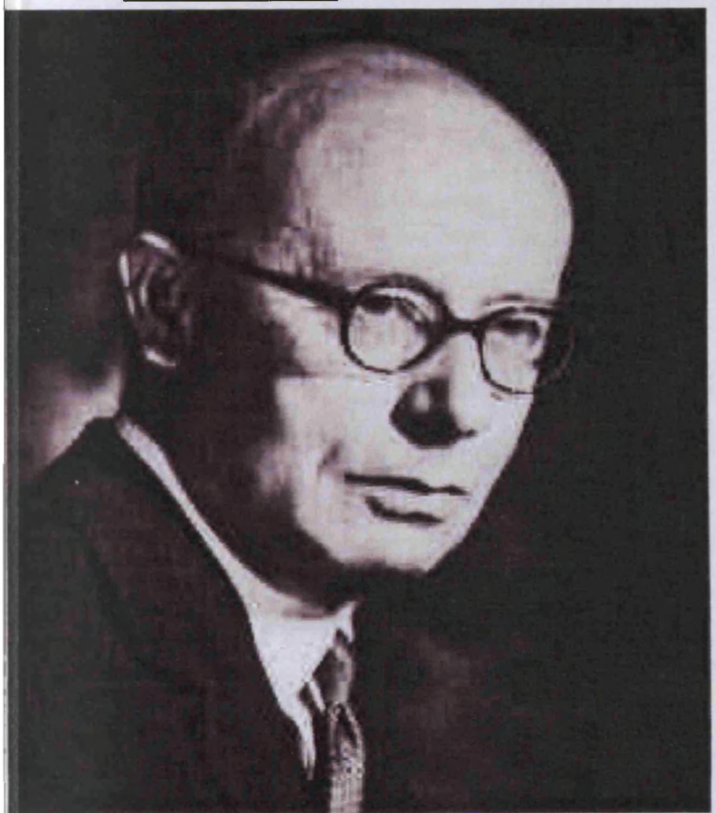


Fig 3.106 Max Newman
www.fc.up.pt

It was Max Newman who came up with a response, a way forward to crack the Lorenz code. Using Turing's paper on computable numbers, Newman came up with a way of to mechanise the cryptanalysis of the Lorenz cipher. He designed a machine that could adapt itself to different problems. Today we have a different name for a machine of this nature. We call it a programmable computer.

CUT TO

THREE SC 125

The senior staff at Bletchley were of one mind: they didn't believe it was technically possible to implement Newman's design. The result was the project was shelved.

Fig 3.107 Bletchley Park
www.en.wikipedia.org
CUT TO

THREE SC 126

But they had not contended with an Engineer called Tommy Flowers. Flowers had been involved in the discussions for Newman's machine and decided to ignore their views.

Fig 3.108 Tommy Flowers
www.connected-earth.com/
CUT TO

THREE SC 127

At the Post Office research Centre at Dollis Hill in North London, Flowers used Newman's blueprint and spent ten months building his programmable machine called Colossus.

Fig 3.109 Dollis Hill
www.cowfish.org.uk
CUT TO

THREE SC 128

Tommy Flowers delivered Colossus to Bletchley on Dec 8, 1943.

Fig 3.110 Tommy Flowers on rhs
www.virtualmuseum.dlib.vt.edu
CUT TO

THREE SC 129

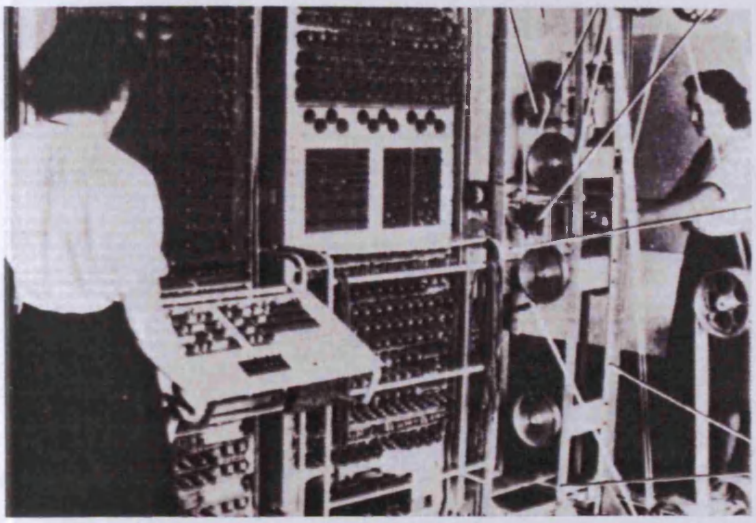


Fig 3.111 A Picture of The Colossus Computer
www.people.bath.ac.uk
CUT TO

It was made up of 1500 electronic valves but the most important fact was that it was programmable and this made it the world's first programmable computer significantly it worked, it did crack Lorenz; another victory for the code breakers, but what of the future?

THREE SC 130

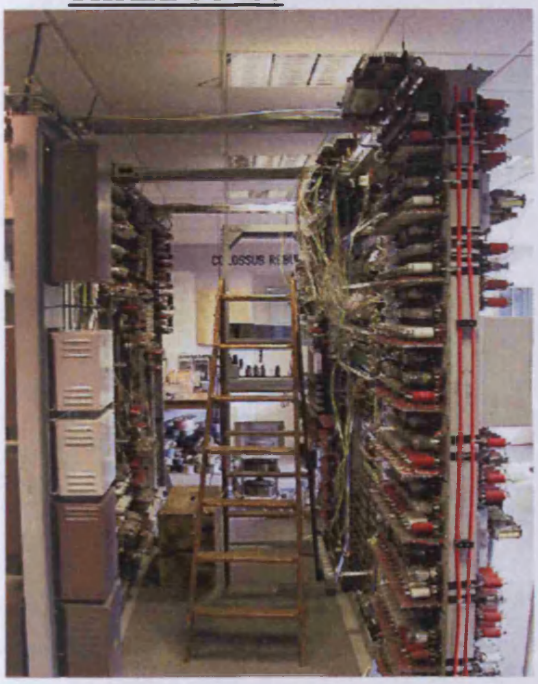


Fig 3.112 The rebuilt Colossus now on show at Bletchley Park
www.angelfire.com

CUT TO

At the end of the war, everything, including Colossus, was destroyed by order of the government of the day and Tommy Flowers did his duty, by burning the blueprints to Colossus. So the plans for the world's first computer were lost forever.

THREE SC 131

However, in the mid-1990's plans were developed to rebuild a working replica of Colossus. On 6 June 1996 the Duke of Kent formally switched on the rebuild that had taken over two years to complete.

Fig 3.113 HRH Duke of Kent
www.churchill-society-london.org.uk/

CUT TO

THREE SC 132

The need for secrecy over Colossus was understandable, if you think about it. At the end of the Second World War, we see the development of the arms race and the so-called Cold War between the Russians and the Americans. This was the reality in which the code-breakers were about to move into.

Fig 3.114 Secrecy soviet union
www.fas.org www.cheguevara.itgo.com

CUT TO

THREE SC 133

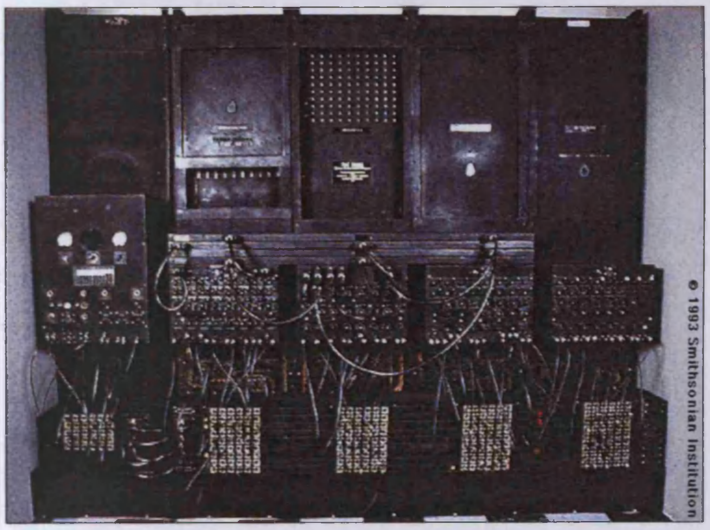


Fig 3.115 The ENIAC
www.photo2.si.edu
CUT TO

It also meant that in historical terms there are counter-claims to who was first to build a computer. For example, in 1945, two Americans called Eckhart and Mauchly developed Eniac, the Electronic Numerical Integrator and Calculator. This was a machine that consisted of 18 000 valves and it could perform 5000 calculations per second. This was a remarkable achievement and for many decades it was believed that Eniac was the first computer, but in reality it was not. Colossus was the first but was a secret. This does not detract from Eckhardt and Mauchly's achievement, for they were both remarkable men.

THREE SC 134

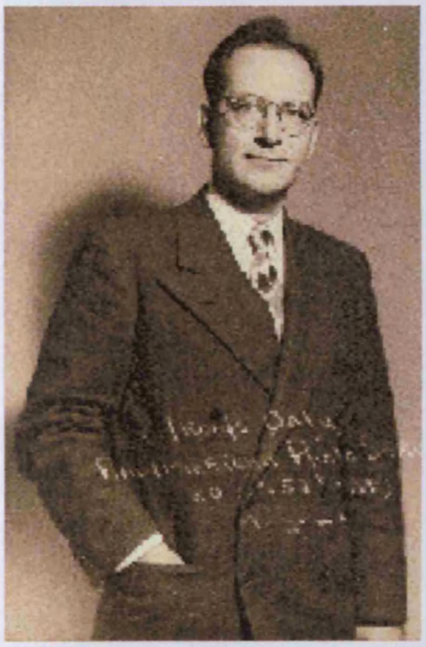


Fig 3.116 Photograph of John W. Mauchly, ca. 1940-50
www.library.upenn.edu
CUT TO

During World War II, Mauchly went to the Moore School of Engineering at the University of Pennsylvania and took an electronics course. He is said to have found the class fairly easy, but formed a good relationship with J. Presper Eckert, his lab instructor. The two of them began working together to build ENIAC under an army contract. At this time no one in the world of mathematics research had ever even heard of Mauchly.

THREE SC 135

J Presper Eckert Jr. graduated in 1937, and then he entered the Moore School of Electrical Engineering at the University of Pennsylvania. He was an outstanding electrical engineer and built Eniac with Mauchly. Mauchly concentrated on the overall design while Eckert constructed the electronic circuits. The machine would later prove invaluable for scientists at Los Alamos and the development of nuclear weapons.
So again we see how the solution for contemporary problems becomes the starting point to solve further problems, later in the history of mathematics and science.

Fig 3.117 John Presper Eckert
www-groups.dcs.st-and ac.uk
CUT TO

THREE SC 136

So what happened to the code-breakers? Some stayed on and went to Cheltenham, to the new GCHQ in 1952. Many went back to civilian life but all were forbidden to discuss what they had done during the war. To many it was an enormous handicap but one they had to bear.

Fig 3.118 GCHQ aka the doughnut, Cheltenham

www.designbuild-network.com/
CUT TO

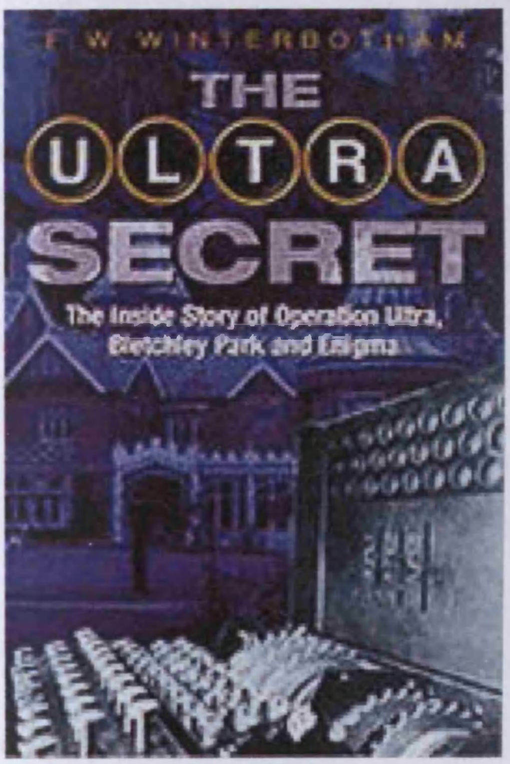
THREE SC 137

In 1982 the Navajo Code Talkers were honoured by the US government who declared 14 August as National Navajo Code Talkers Day. The next stage in code-breaking was to develop the use of machines.

Fig 3.119 US National Code Talkers Day
www.theguys.org

CUT TO

THREE SC 138

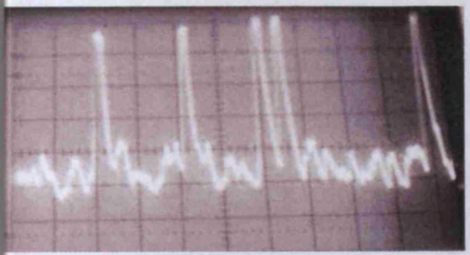


After the war Britain had a major security advantage in that it knew how Enigma worked. The British had captured many thousands of Enigma machines by then and freely distributed them amongst the Commonwealth countries, and spent the next thirty years reading the transmissions of these countries. It was only when the Commonwealth countries stopped using these machines in the 1970's that the Government gave permission for Captain F.W. Winterbotham to write *The Ultra Secret* that the truth became widespread.

Fig 3.120 Ultra Secret
www.bookweb.kinokuniya.co.jp

CUT TO

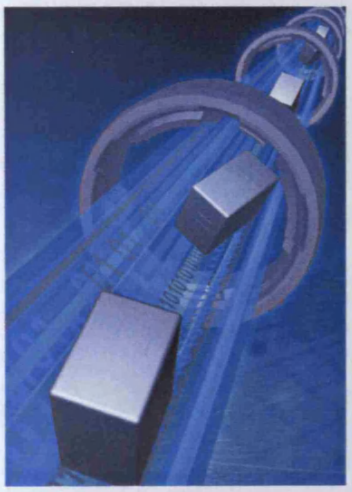
THREE SC 139



The need for codes and ciphers are far greater now in modern society than ever before than simply because of the Internet.

Fig 3.121 Internet
www.fraunhofer.de
CUT TO

THREE SC 140



Every time a transaction takes place on the Internet, the security is dependent on mathematics and in particular on prime numbers.

Fig 3.122 Real Digital Signal
www.people.deas.harvard.edu
CUT TO

THREE SC 141

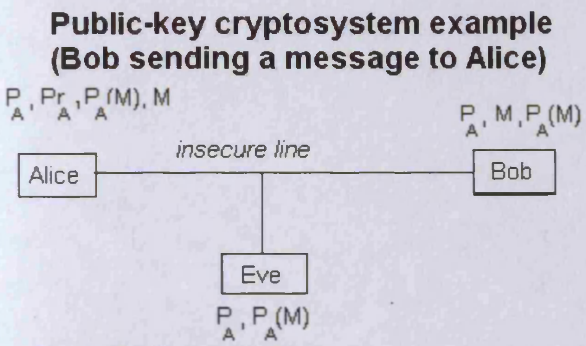


Fig 3.123 Bob and Alice
www.math.cornell.edu
CUT TO

Think of it like this. There are two people that are known in the computer industry as Bob and Alice. Imagine Alice wished to send a message to Bob without anyone else being able to read it.
The mathematicians came up with a theory that is best thought of in terms of padlocked boxes.

THREE SC 142

Fig 3.124 key.
www.medicalarchives.jhmi.edu
CUT TO

Imagine Alice want to send Bob a message. She padlocks it into the box but she somehow has to get the key to Bob, so that he can open the box.

THREE SC 143

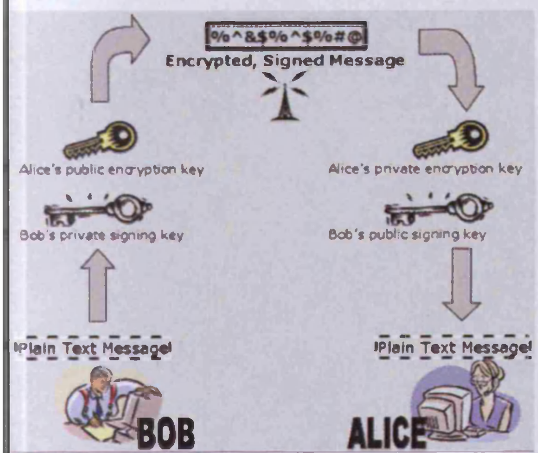


Fig 3.125 Online Security
www.naa.gov.au
CUT TO

But one way forward would be for Bob to padlock the box and send it back to Alice. She could then remove her padlock and send it back to Bob. Remember Bob has a padlock on the box now, so it is still secure. But

THREE SC 144

this is hardly an ideal solution. It means that the message has to be sent back and forth

Fig 3.126 Sending messages
www.humsci.auburn.edu
CUT TO

THREE SC 145

But imagine if Alice could go and buy a Bob padlock. Once she had put the padlock on the box, it would be locked and since Bob is the only person to possess the key, he would be the only person to be able to open the box.

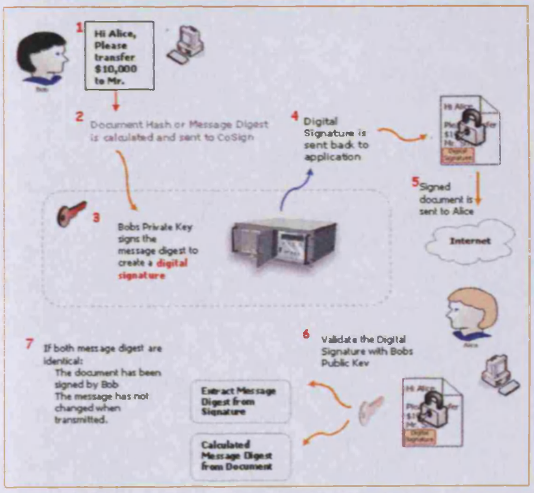
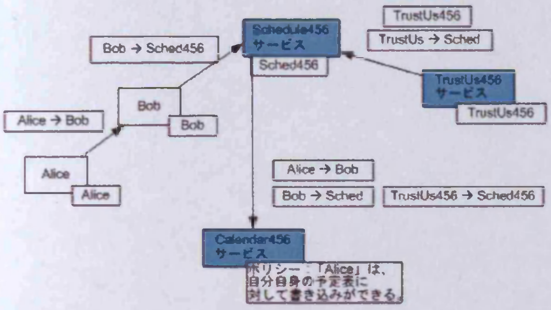


Fig 3.127 Bob and Alice
www.arx.com
CUT TO

THREE SC 146



This is exactly what they have done but mathematically. By using certain mathematical functions, the mathematical equivalents of putting padlocks onto the box, it is now possible to have secure encryption. People now have two keys their public key and their private key.
So think of the public key as the padlock. In effect, this means that you can get as many copies as you like of another person's padlock but only that person has the key. So you acquire their public key, from various locations on the Internet.
You apply their key to the message, which encrypts the message. You then send the message to the other person who can then decrypt the message.

Fig 3.128 Alice □ Bob □ Alice
www.microsoft.com

CUT TO

THREE SC 147

Fig 3.129 British Bobby helmet
www.sieglers.com

FADE TO CREDITS

But all of this development has not been popular with the Law Enforcement authorities around the world. The problem with encryption that is too good is that, according to some people, criminals can take advantage of the use of the Internet to commit illegal acts, even on an international scale.
The argument between the liberalists who say that Internet should be a free zone and the authoritarians still rumbles.
What is true is that the need to understand patterns and rules has never been greater and what we need to be clear about is that throughout history we have used codes, and in mathematical terms, this means algebra, to solve contemporary problems. This is because the universe in which we live operates to simple mathematical laws. This fact helps us make sense of and understand the world because the mathematics makes that understanding possible.

Programme Four

The Language of the Universe

In the Footsteps of Euclid

Four Sc 1

[WE SEE THE SUN RISE OVER THE GLOBE, WITH THE NOW ESTABLISHED PROGRAMME OPENING SHOTS. WE SEE THE PROGRAMME TITLES COME ONTO THE SCREEN]

Most people can remember geometry from their schooldays, but what is geometry?
Geometry is a vast area of study and we could not possibly cover every part, so we will concentrate on one general area, including triangles and why triangles are so important.

CUT TO

Four Sc 2

To understand this we need to go back in time, about 2000 years, to the Nile in Egypt.

Welcome to Egypt, but why is Egypt so important to our story? Egypt is important because it was here that humans recorded one of the earliest needs to measure the earth: the need to use geometry.

Fig 4.1 Map of the length of the Nile
www.specialtyinterests.net

CUT TO

Four Sc 3

Geometry means the physical measurement of the Earth and it is to here, in Egypt, even though the Greeks gave us a great deal of geometry, that we need to look for early developments in geometry.

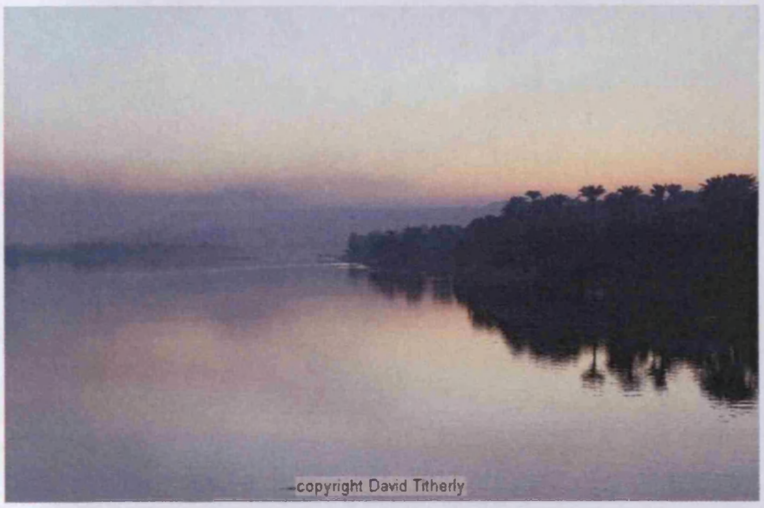
Fig 4.2 Geometry
www.csupomona.edu
CUT TO

Four SC 4

Egypt is important because Egypt was a source of knowledge for one special reason in particular,

Fig 4.3 Geometry symbolism in Egyptian culture
www.constructingtheuniverse.com
CUT TO

Four SC 5



the River Nile.

Fig 4.4 The River Nile
www.titherly.com
CUT TO

Four SC 6

The Priests in Ancient Egypt had knowledge of something that was vital to the farmers, the rise and fall of the river. It was this rise and fall of the river that had a major effect on the mathematical knowledge of that time.

Fig 4.5 Priests of Ancient Egypt
www.touregypt.net
CUT TO

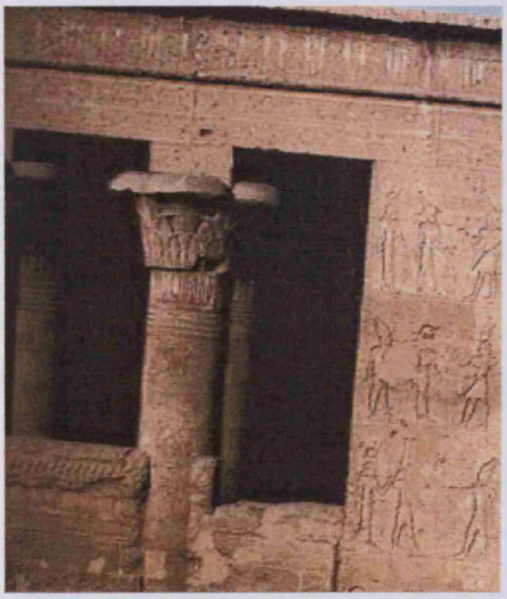
Four Sc 7

The rise and fall of the Nile affected the economy of the area, and the very way of life itself. It meant that crops could be gathered safely or ruined if the predictions were wrong. Those that could make the predictions, the Priests, held immense power and they used it.

Fig 4.6 Priests of Egypt
www.maa.missouri.edu

CUT TO

Four Sc 8



And it was this knowledge of how the river affected the economy that attracted the Greeks. They came here to find out exactly how the Egyptians measured the Earth.

Fig 4.7 Greeks in Egypt 0 to 500 BC
www.suziemanley.com

CUT TO

Four SC 9

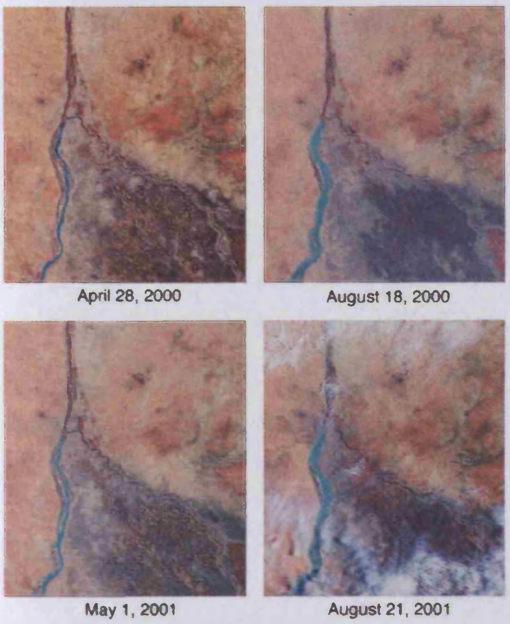


Fig 4.8 Flooding along the Nile river.
www.eosweb.larc.nasa.gov

CUT TO

But why measure the Earth? The answer lies in the fact that the rise and fall of the river meant that there was yearly flooding of the Nile. So planning was essential. It was essential because if no crops became available, people starved. But there was another reason and that involved money.

Four SC 10

Fig 4.9 Flooding along the White Nile
www.gesource.ac.uk

It was this regular flooding that caused the need to develop the ability to measure the Earth. Geometry was important because after the annual flood the land boundaries became blurred and so had to be re-defined and re-marked. Since a farmer was taxed on the amount of land he worked, there was a need to get it right.

CUT TO

Four Sc 11

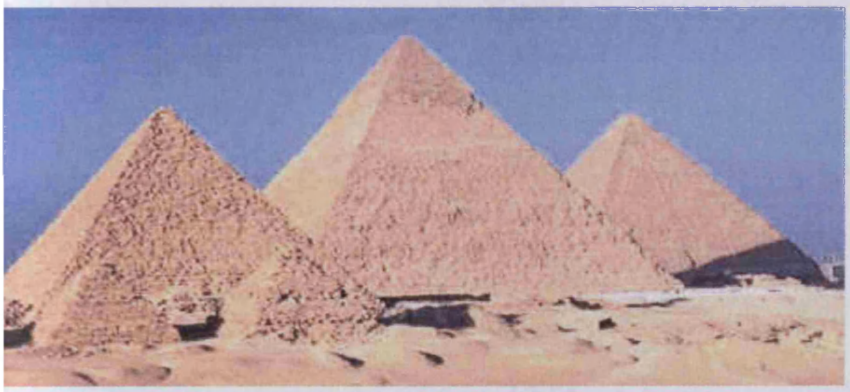


Fig 4.10 Great Pyramids of Egypt
www.mathsisfun.com
CUT TO

The Egyptians had undoubtedly learnt a lot of mathematics in building the pyramids and it was this ability to measure that attracted the Greeks. But why are the Greeks important at all? After all, it was the Egyptians who built the pyramids, so what did the Greek early mathematicians contribute? The Greeks are important in the history of mathematics for one reason - they recorded mathematics in writing and this is our avenue to ancient knowledge. One such writer was called Thales.

Four SC 12

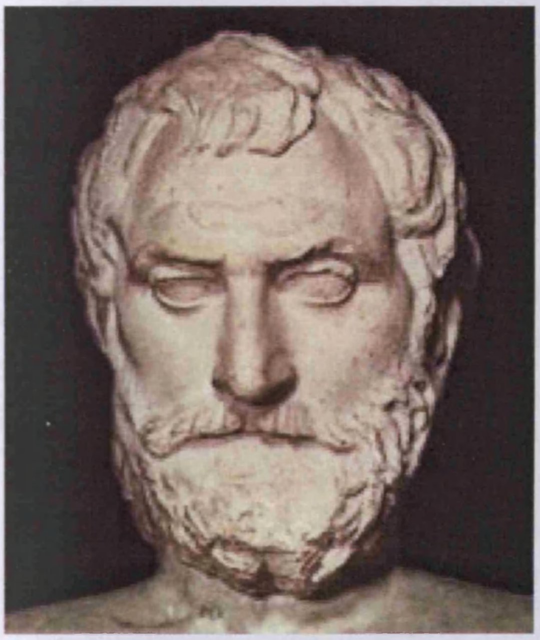


Fig 4.11 Thales
www.tpaweb.org

This is Thales. He was a merchant with knowledge of engineering. In many ways this is a disservice to him because he was a major influence in the history of mathematics. He travelled far and wide in Egypt.

CUT TO

Four SC 13

Fig 4.12 The Great Pyramid
www.europa.com

In the course of his travels, he computed the height of the Great Pyramid, he made experiments with amber and is credited as making the first observations on electrical attractions.

CUT TO

Four SC 14

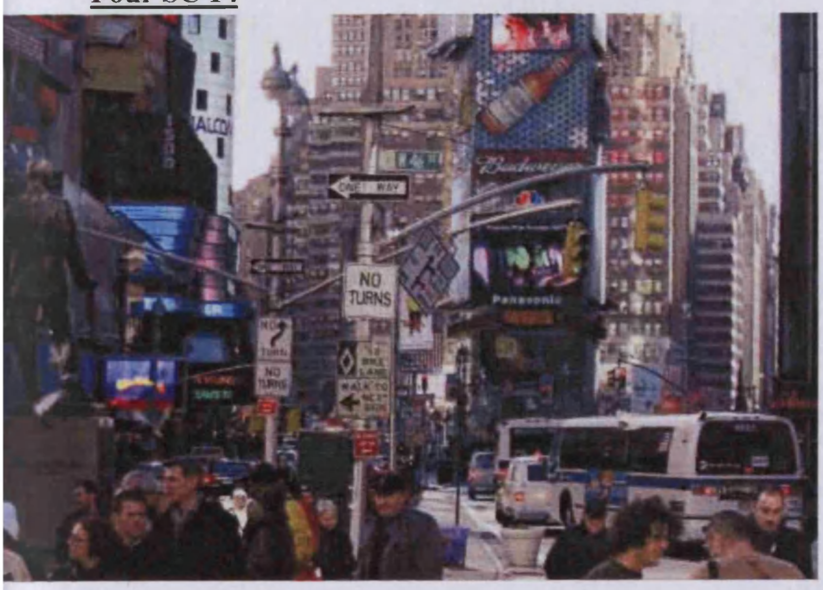
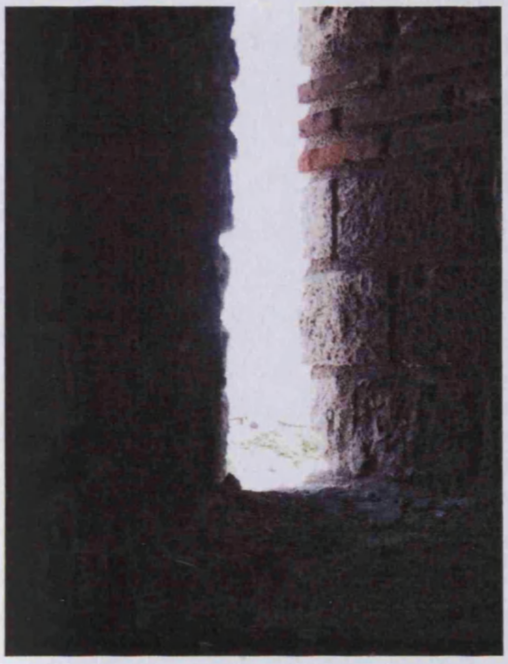


Fig 4.13 Cities
www.coe.west.asu.edu

But why was it so important for early mathematicians to be able to compute heights like this? To understand why early mathematicians needed to calculate in this way, we need to consider life at that time. In the 21st Century we choose to live mainly in urban areas, with plenty of artificial light, so it is difficult to imagine the importance of light and shadow in the early civilisations.

CUT TO

Four Sc 15

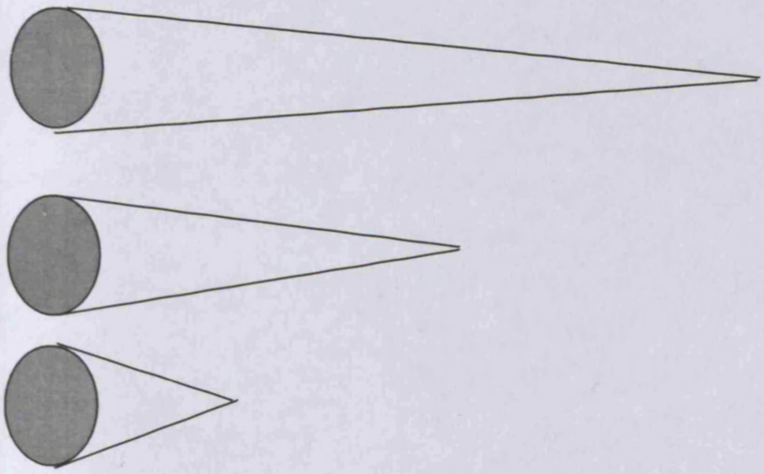


The first city dwellers had windows that were narrow slits, which allowed both sunshine and moonlight to enter the home. These narrow slits for windows kept homes cool in hot weather and warm in cooler weather. The rays played upon the interior and made shadows crisp and sharp. The people at this time did not need to be told that light travels in straight lines or that light rays from a very distant object slopes so little, that they could be treated as parallel, since it was part of their daily experience.

Fig 4.14 Narrow - slit windows
www.campbellholt.com

CUT TO

Four Sc 16



The further away that a heavenly body is situated, then the smaller is the angle between the light rays that come from the extreme edges. This is how they can be treated as more or less parallel. This means that we can start to develop some mathematics and make some measurements, and that is what Thales did to measure the height of the pyramid.

Fig 4.15 Conics

CUT TO

<u>Four Sc 17</u>

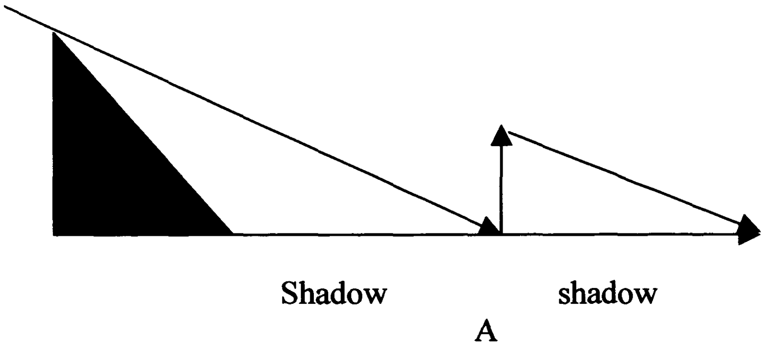


Fig 4.16 Measuring a pyramid

But how did Thales work out the calculation? We have shown the pyramid as a shaded triangle. The left to right downward pointing arrow on the left is the direction of the sunlight. At point A he puts a pole and therefore creates a smaller triangle from a smaller shadow.

<u>CUT TO</u>

<u>Four SC 18</u>
[ON THE SCREEN IT SAYS]
WHAT DO WE KNOW?
THE HEIGHT OF THE POLE
THE LENGTH OF THE SMALLER SHADOW
THE LENGTH OF THE LARGER SHADOW
WHAT DO WE WANT?
THE HEIGHT OF THE PYRAMID

Fig 4.17 Stating the problem

From this we want to know the height of the pyramid. We know the height of the pole, so we can set up an equation.

<u>CUT TO</u>

<u>Four SC 19</u>
[WE SEE A CLOSE UP OF THE COMPUTER SCREEN]

$$\frac{pyramid\ height}{large\ shadow} = \frac{pole\ height}{small\ shadow}$$

Fig 4.18 Setting up the equation

From this we can work out an equation.
This works because both triangles are similar.
From this we get this equation.

<u>CUT TO</u>

<u>Four SC 20</u>
[WE ARE STILL LOOKING AT THE COMPUTER SCREEN AS IT CHANGES TO SHOW]

So, by using this equation we can again use the power of mathematics to use the facts we know, to generate something we did not previously know.

$$\frac{pyramid\ height}{l\arg e\ shadow} = \frac{pole\ height}{small\ shadow}$$

Fig 4.19 Re-arranging the equation

<u>CUT TO</u>

<u>Four SC 21</u>
[WE SEE A CLOSE UP OF THE COMPUTER SCREEN]

$$MID\ HEIGHT = \frac{LARGE\ SHADOW * POLE\ HEIGHT}{SMALL\ SHADOW}$$

From this we can work out an equation. This works because both triangles are similar
So how tall is the Great Pyramid? The answer is approximately 146 metres high but it has weathered over the years and that has reduced the height slightly.

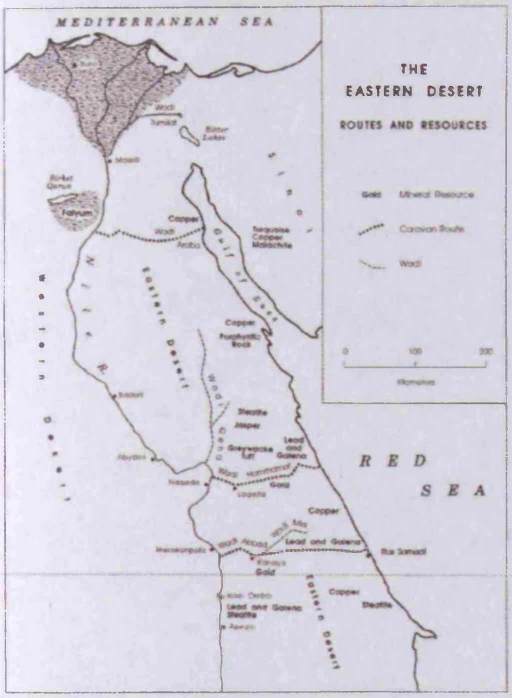
Fig 4.20 Setting up the equation

Four Sc 22

As trade travels, so does knowledge. As caravans carry their wares of trade, they need to use the weights and measures, in the selling process. So this means that methods of calculating must also travel.

Fig 4.21 Caravan crossing the Desert
www.rehsgalleries.com
CUT TO

Four Sc 23



So it was Arab tradesmen travelling to Western Europe from Asia that brought their mathematical techniques and ideas. That is why the numbers we use today are called Arabic numerals. This is also how other parts of mathematics travelled to Europe, for example, Pythagoras' rule, involving triangles, which most people study at school. That's the one where children learn that the square on the hypotenuse or longest side of a right-angled triangle is equal to the sum of the squares on the other two sides.
But surprisingly, in historical terms, the reason we know this so well is because of another man, Euclid.

Fig 4.22 Trade routes to the Red Sea
www.egyptorigins.com
CUT TO

Four Sc 24

Fig 4.23 Euclid.
www.hometown.aol.com
CUT TO

Euclid was one of the finest of the early Greek mathematicians and is often referred to in the history of mathematics as the father of geometry. The reason for this is simple; he wrote a very important book that was one of the finest works in mathematics. In this book he set out definitions, postulates and common notions of the most basic geometrical terms and explained the mathematics that came from these definitions. A postulate or axiom is a basic assumption or a rule that seems obvious and can therefore be accepted without proof.

Four Sc 25

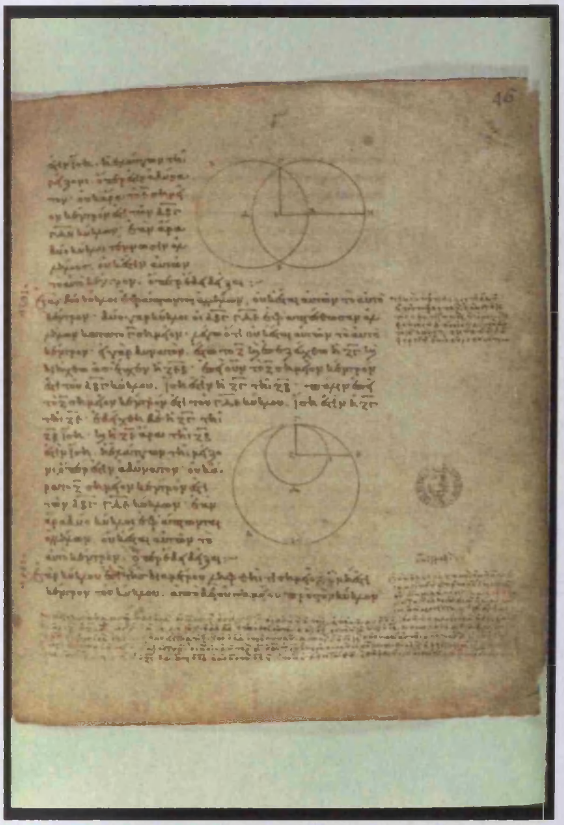
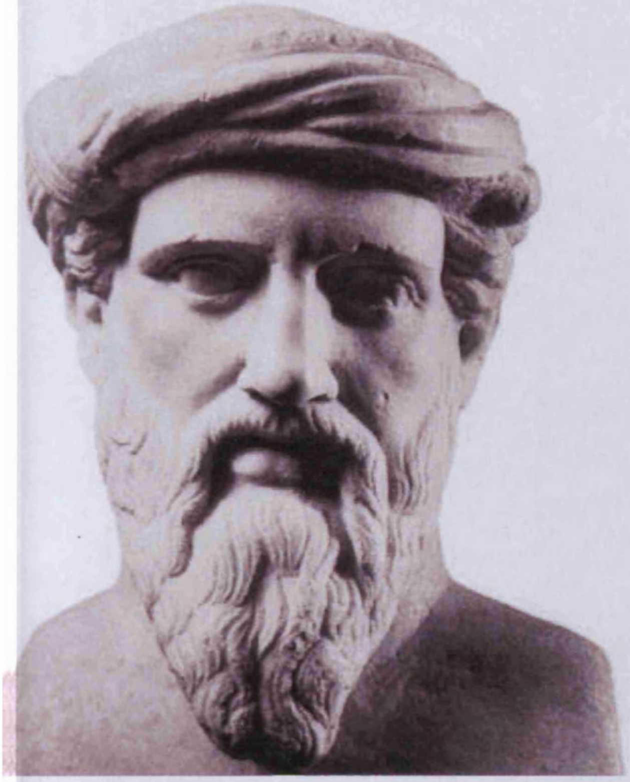


Fig 4.24 Euclid's Elements:
www.rsl.ox.ac.uk
CUT TO

Euclid's book is called *The Thirteen Books of the Elements* but it was not all original work. It seems likely that he used the first great Greek mathematician, Thales, as a source. Even so, *The Elements* has proven to be a model for mathematics writing and research for millennia.

Four Sc 26



So it was Euclid who tells us of Pythagoras - but who was Pythagoras and why was his work on triangles so important, and how did it link a French mathematician who was born in 1601 to the world's most famous mathematical problem, and a mathematician working in 1993, and 15th - century castles and cannonballs?

Fig 4.25 Pythagoras
www.epsilones.com
CUT TO

Four Sc 27

It was here on Samos in the Greek Islands that Pythagoras was born in about 580 BC.

Fig 4.26 Samos Island
www.samos.gr
CUT TO

Four Sc 28

Pythagoras' life is a mystery. There is no written first-hand account of his life and so he is shrouded in legend. It is difficult to separate fact from fiction but what is sure is that he studied a lot of mathematics, not just triangles, and that he taught his followers to believe that numbers control nature.

Fig 4.27 Pythagoras
www.did.mat.uni-bayreuth.de

CUT TO

Four Sc 29

What exactly did Pythagoras mean by controlling nature? Pythagoras believed that numbers were the basis of the whole of life, both human - oriented activity and naturally occurring activities. For example, in terms of human activity, Pythagoras discovered a basic relation between musical harmony and mathematics. When a single string is stretched, it vibrates as a whole and produces a ground note.

Fig 4.28 Chicago harpist Courtney Lawhn
www.chicago-harpist.com

CUT TO

Four Sc 30

The notes that sound harmonious with it are made when the string is divided into two equal parts and then three equal parts and so on. If the still point on the string is not at one of these equal points, then the note sounds discordant to our ears.

Fig 4.29 Member of Harpist Yorkshire
www.harpist-yorkshire.co.uk
CUT TO

Four Sc 31

The notes that are harmonious are produced when we reach the defined points. If you start with the whole string, this is the ground note. When the node is moved to the midpoint, this is an octave above. If you move it to one third of the way along, then the sound is a fifth above that.

Fig 4.30 Harmony
www.elfwood.lysator.liu.se
CUT TO

Four Sc 32

Pythagoras had found that chords, which sound pleasing to the Western Ear, are exact divisions of the string by whole numbers.

Fig 4.31 Pythagoras.
www.astrologycom.com

CUT TO

Four Sc 33

Remember, Pythagoras believed that numbers were the basis of all human and life and nature. It was this link, between nature and number, which was so important. Pythagoras and his followers were convinced that all of nature was controlled by the simplest of numbers, if only they could be found.

Ammophila arenaria

Fig 4.32 Natural vegetation
www.coastalguide.org
CUT TO

Four Sc 34

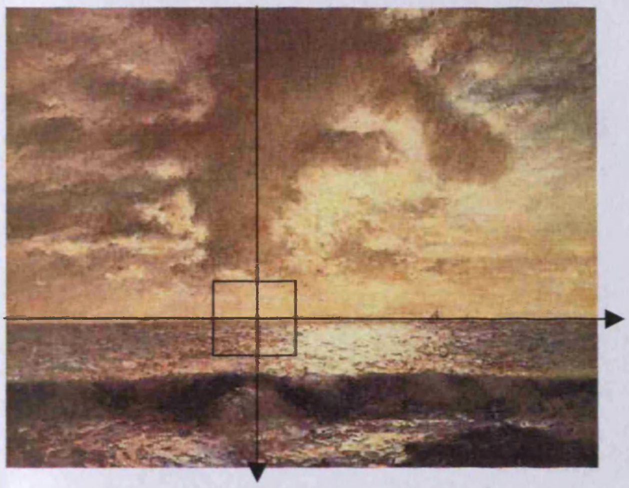
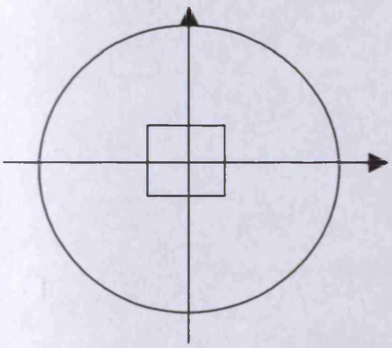


Fig 4.33 Horizon sunset
www.canvasartprints.com

So Pythagoras proved that sound was governed by exact numbers. He then went on to prove that this was also true for the world of vision.
We base our visual world on two experiences. The first is that gravity is vertical and the second is that the horizon is at right angles to gravity. Think of these as cross wires and where they meet, you have formed the right angle.

CUT TO

Four Sc 35



If I now shift in accordance with these lines, and do so four times, I am back where I started, so we are defining a revolution as the sum of four right angles.
Is this important?
Well, yes, it is. It defines the world as we see it and enables us to use it as a mathematical thinking tool.

Fig 4.34 Revolution

CUT TO

Four Sc 36

Fig 4.35 Map of Samos
www.pithagorio.net

So what do we know of Pytahagoras the man? Actually, we know very little. We do know he lived here on the island of Samos and that is important because Samos acted as a gateway of knowledge from Asia to Europe

CUT TO

Four Sc 37

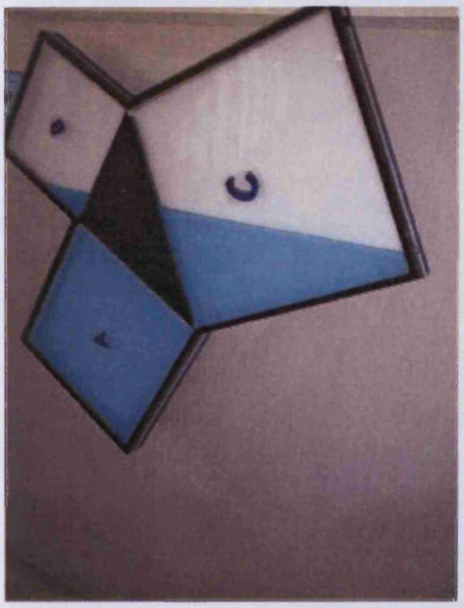


Fig 4.36 Pythagoras' theorem
www.xperiment.se

But it is for his theorem or rule that Pythagoras is best known. It is the rule that every child has to learn in school. But although he is credited with it, it was most certainly known to the Chinese and the Babylonians before Pythagoras came to it. So what exactly is the theorem of Pythagoras?

CUT TO

Four SC 38
[WE SEE A COMPUTER SCREEN. ON THE SCREEN THE FOLLOWING DIAGRAM CAN BE SEEN]

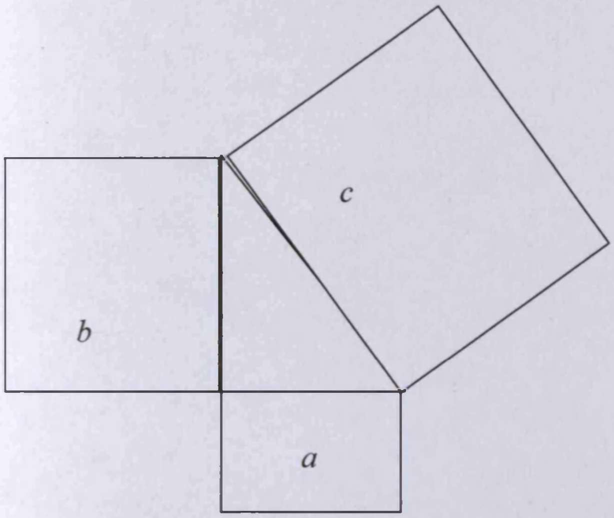


Fig 4.37 Theorem of Pythagoras
CUT TO

This is the famous 3,4,5 triangle that you undoubtedly studied at school, but why is it significant?
Here we can see that there is a square drawn on each side of the triangle, but what Pythagoras found was more significant than that. If we add the areas of the smaller squares, they are exactly equal to the area of the larger square. So the area of square *c* is exactly equal to the areas of *a* and *b* added together. We will look at numbers shortly.
The important point here is to notice that Pythagoras had proved a general theorem. In other words, this becomes a general law that applies to every right-angled triangle.
This theorem then becomes probably the most important theorem in mathematics.

Four Sc 39
[WE SEE A CLOSE UP OF THE COMPUTER SCREEN SHOWING]
$5^2 = 3^2 + 4^2$

Fig 4.38 Pythagorean Triple
CUT TO

So how exactly does Pythagoras work? Well for example, take the 3:4: 5 triangle mentioned earlier.

The longest side of the triangle is the hypotenuse and for Pythagoras to be true, we would need to find that there is a connection between the longest side, the hypotenuse and the other two sides, and indeed there is. Look at the numbers:
five squared is 25,
three squared is 9 and
four squared is 16.
And
25 = 9 + 16

So Pythagoras works.

Four Sc 40

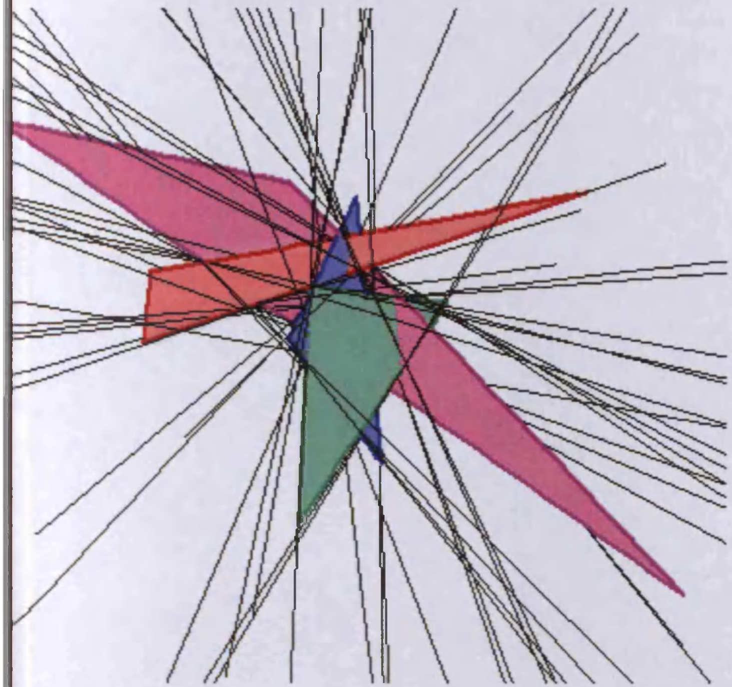


Fig 4.39 Triangles in three-dimensional space
www.math.tamu.edu
CUT TO

Pythagoras had not only found a link in the now famous 3,4,5 triangle but he had found a link in every triangle that is right-angled. This link is still exploited today by many builders who use the 3,4,5, triangle to guarantee that the angle at which the walls they are building meet is 90 degrees. This is the genius of this rule or theorem: what Pythagoras did was to find numbers that describe the exact laws of the universe. He had linked the world of numbers to the world in which we live in, the world of three-dimensional space.

Four Sc 41

Fig 4.40 Fermat à Beaumont de Lomagne, Fermat's Birthplace
www.home.nordnet.fr
CUT TO

Knowledge travels many different roads through history and one important route was to link Pythagoras with a French mathematician who was born here in Beaumont de Lomagne in Southwest France.

Four SC 42

Fig 4.41 Pierre de Fermat
www.fr.wikipedia.org

In 1601 on August 20th, a child had been born in this house, who was to infuriate mathematicians for 300 years after his death. His name was Pierre de Fermat.

CUT TO

Four Sc 43

Fig 4.42 Pierre de Fermat
www.mathematik.ch

Fermat became a civil servant and he had additional duties, which included service to the judiciary. He served as a judge and dealt with severe cases and rose extremely quickly through the ranks. As we shall see, his legal duties had an effect on his mathematics.

CUT TO

Four Sc 44

Interestingly, mathematics was almost deprived of this genius. In 1652 Fermat caught the plague and was seriously ill. In fact he was so ill that a friend publicly proclaimed he had died to several colleagues and was later forced to withdraw the statement. He wrote to a friend:
'I informed you earlier that our good friend Fermat was dead. He is still alive and we no longer fear for him even though we had counted him amongst the dead a short time ago. The plague no longer rages amongst us'.
So Fermat survived to work in law and develop what he felt was an interesting hobby.

Fig 4.43 Beaumont de Lomagne
www.bastidess.free.fr

CUT TO

Four SC 45

Although his work occupied a great deal of his time, what spare time Fermat had was devoted to mathematics. This was his hobby and since French judges were barred from fraternising with the locals, in case a friend came up before the bench, it meant he could spend time studying mathematics. But Fermat had a bad habit.

Fig 4.44 Pierre de Fermat 1601-1665
www.microscopy.fsu.edu
CUT TO

Programme Five

The Language of the Universe

The Measurement of Uncertainty

Programme Notes

Programme One

Sources Consulted

1 Bronowski J. 1973 *The Ascent of Man,* BBC: London.

2 Burke J.1978 *Connections,* Macmillan: London.

3 Burke J.1985 *The Day the Universe Changed,* BBC: London.

4 Fauvel J. and Gray J. 1987 *The History of Mathematics,* Macmillan: London.

5 Hogben L. 1938 *Mathematics for the Million,* Unwin: London.

6 Hogben L. 1938 *Science for the Citizen,* Unwin: London.

7 Joseph G.G. 1991 *The Crest of the Peacock: Non-European Roots to Mathematics,* IB Taurus: London.

8 McCleish J. 1991 *Number,* Bloomsbury: London.

9 Snowden B. *The Curious History of the Gregorian Calendar,* http://www.infoplease.com/spot/gregorian1.html accessed 12/04/99

10 Woolley B. 1999 *The Bride of Science,* Macmillan: London.

11 Zaslavsky C. 1990 *Africa Counts,* Lawrence Hill: Chicago.

Illustrations

Internet Sources and Websites

Programme One

Fig	Description	Website reference
1.1	Red Sky in the Morning .	www.artshole.co.uk
1.2	Eiffel Tower.	www.ashlintree.com
1.3	Flowers.	www.dpfwiw.com
1.4	Frozen scene.	www.aquarticles.com
1.5	Miss Milbanke, future wife of Byron.	www.engphil.astate.edu
1.6	Lady Caroline Lamb and Byron.	www.gothicpress.freeserve.co.uk
1.7	Three mast full rigged sailing ship.	www.schoonerman.com
1.8	Babbage's Difference Engine.	www-groups.dcs.st-and.ac.uk
1.9	Native Americans.	www.nativeamericans.com
1.1	John Napier.	www.katev.org
1.11	The author.	www.studymates.co.uk
1.12	Galileo Quotation.	author-produced slide
1.13	Title slide.	author-produced slide
1.14	Sky.	www.nesky.org
1.15	Map of Africa.	www.bnbguidebook.
1.16	Mists of Time.	www.flickr.com
1.17	Mary and Louis Leakey.	www.leakeyfoundation.org
1.18	Ancient human jawbone.	www.bbc.co.uk

1.19	Ancient Mine.	www.themodernantiquarian.com
1.20	Cave paintings.	www.tony.lownds.com
1.21	Lake Edward.	www.ilec.or.jp
1.22	The Ishango bone.	www.naturalsciences.be
1.23	The Ishango Bone.	www.tacomacc.edu
1.24	Shells.	www.daleyplanit.com
1.25	Complex fractal pattern.	www.members.aol.com
1.26	Jean de Heinzelin .	www.naturalsciences.be
1.27	Marshack.	www.donsmaps.com
1.28	Digital Moon.	www.homepage.mac.com
1.29	Lake Edward.	www.ilec.or.jp
1.30	Africans.	www.radiosportfm.com
1.31	Florence.	www.bardill.net
1.32	Florence.	www.orcca.on.ca
1.33	Roman soldier.	www.web.grestone.bham.sch.uk
1.34	Roman Numerals.	author-produced slide
1.35	Roman soldier.	www.dspace.dial.pipex.com
1.36	Roman Numerals 2.	author-produced slide
1.37	Roman Numerals 3.	author-produced slide
1.38	Roman Numerals 4.	author-produced slide
1.39	Roman Numerals 5.	author-produced slide
1.40	Roman Numerals 6.	author-produced slide
1.41	Florence.	www.thomashawk.com
1.42	Arab man.	www.toursaudiarabia.com
1.43	Whole earth.	www.uni-mainz.de
1.44	Babylon.	www.heartlight.org
1.45	Arabic Numerals 1.	author-produced slide
1.46	Arabic Numerals 2.	author-produced slide
1.47	Arabic Numerals 3.	author-produced slide
1.48	Arabic Numerals 4.	author-produced slide
1.49	Arabic Numerals 5.	author-produced slide
1.50	Padua University.	www-drecam.cea.fr
1.51	Sands of time.	www.eternelpresent.ch
1.52	Ancient coin.	www.geldmuseum.de
1.53	Weights and Measures.	www.state.in.us
1.54	Money.	www.gallery.prwdot.org
1.55	Native Americans.	www.chgs.umn.edu
1.56	Native Americans.	www.scls.lib.wi.us
1.57	Maya culture.	www.wildland.com
1.58	Satellite map of North America.	www.motherplanet.net
1.59	Native Americans.	www.memory.loc.gov
1.60	Quipu.	www.instruct1.cit.cornell.edu
1.61	Pearl Harbor Hawaii.	www.celestiamotherlode.net
1.62	Metal money.	www.fotosearch.com
1.63	Coins.	www.artlebedev.ru
1.64	Clock.	www.csh.rit.edu
1.65	Police officer.	www.hulubei.net
1.66	Lunar Month.	www.ejphoto.com
1.67	Caesar.	www.thepaolas.com
1.68	Egyptian statue of Cleopatra.	www.nationmaster.com
1.69	Julius Caesar.	www.de.wikipedia.org
1.70	365.25 days in a year.	www.factbook.org
1.71	Vatican.	www.time.com
1.72	Council of Trent.	www.ignatiushistory.info
1.73	Pope Gregory XIII.	www.ronaldbrucemeyer.com
1.74	Gregorian calendar.	www.allourhistory.com
1.75	Painting.	www.accesshub.net
1.76	Stonehenge, thought by some to be a	www.studyabroad.msu.edu

	calendar.	
1.77	The Cast Iron Numbers Sundial.	www.get2buynow.com
1.78	John Napier.	www.heritage.scotsman.com
1.79	Catholic Sites.	www.glasgow.world-guides.com
1.80	Difficulty in multiplying.	author-produced slide
1.81	Tree - lined avenue.	www.aboutcapetown.com
1.82	Avenue.	www.mistersf.com
1.83	Mathematics.	www.francis.edu
1.84	Powers.	author-produced slide
1.85	Arithmetic progression.	author-produced slide
1.86	Powers 2.	author-produced slide
1.87	John Napier.	www.kartozoologi.no
1.88	Powers 3.	author-produced slide
1.89	Powers 4.	author-produced slide
1.90	Logs.	author-produced slide
1.91	Logs 2.	author-produced slide
1.92	John Napier.	www.mat.usal.es
1.93	Sailing Ship.	www.pspl.on.ca
1.94	Tycho Brahe.	www.measure.igpp.ucla.edu
1.95	Johannes Kepler.	www.kepler.nasa.gov
1.96	Charles Babbage.	www.dma.eui.upm.es
1.97	Charles Babbage John Herschel.	www.crowl.org & www.lib.utexas.edu
1.98	London: Big Ben.	www.darknessandlight.co.uk
1.99	Devon.	www.smilodon.plus.com
1.100	Jesus Church, Forty Hill, Enfield.	www.saintmarymagdalene.org.uk
1.101	An 18 th - century Banker.	www.liverpoolmuseums.org.uk
1.102	The Happy Tutor.	www.smith2.sewanee.edu
1.103	Cambridge University.	www.cambridge.world-guides.com
1.104	Charles Babbage 1791 – 1871.	www.arcula.demon.co.uk
1.105	The Cambridge campus.	www.nscs.org
1.106	London bridge.	www.wmich.edu
1.107	Brookfield Precision Engineering.	www.boatsandoutboards.co.uk
1.108	Charles Babbage's difference engine.	www.technology.niagarac.on.ca
1.109	Useful UK Government Information.	www.buyusa.gov
1.110	Big Ben.	www.buyusa.gov
1.111	British Coins.	www.predecimal.com
1.112	19th - century Britain.	www.uk.filo.pl
1.113	Charles Babbage.	www.dma.eui.upm.es
1.114	An evening soirée in progress.	www.rms-gs.de
1.115	Charles Darwin.	www.nmm.ac.uk
1.116	Ada Lovelace.	www.ieee-virtual-museum.org
1.117	Annabella Milbanke.	www.englishhistory.net
1.118	Lord Byron.	www.2020site.org
1.119	Lady Caroline Lamb.	www.born-today.com
1.120	Being 'out' in Victorian society.	www.bustledress.com
1.121	Annabella and Byron.	www.englishhistory.net www.todayinliterature.com
1.122	Dorset Street London c 1900.	www.users.ox.ac.uk
1.123	Babbage's machine.	www-03.ibm.com
1.124	Mary Somerville 1780 –1872.	www.lib.hku.hk
1.125	Burntisland, Fife – Laque commemorating the life of Mary Somerville.	www.burntisland.net
1.126	Mary Somerville 1780 – 1872.	www.lib.utexas.edu
1.127	The genius of women.	www.secondspring.co.uk
1.128	John Couch Adams.	www.starchild.gsfc.nasa.gov
1.129	Ada Lovelace, aged about 19.	www.plus.maths.org
1.130	Ada Lovelace.	www.ieee-virtual-museum.org

1.131	Sir Arthur C Clarke.	www.timskoch.com
1.132	Digital Interface by W Logan Fry.	www.nd.edu
1.33	Bill Gates, courtesy of the Microsoft Corporation.	www.microsoft.com
1.34	Ada Programming Language.	www.silicon-press.com

Programme Two

Sources Consulted

1 Bronowski J. 1973 *The Ascent of Man,* BBC: London.

2 Burke J. 1996 *The Pinball Effect,* Little Brown: New York.

3 Hogben L. 1938 *Mathematics for the Million,* Unwin: London.

4 Hogben L.1938 Science *for the Citizen,* Unwin: London.

5 McCleish J. 1991 *Number*, Bloomsbury: London.

6 Morris R. 1992 *The Edges of Science,* Fourth Estate: London.

7 Pledge H.T. 1966 *Science since 1500*, HMSO: London.

8 Sobel D. 1996 *Longitude,* Penguin: London.

Illustrations

Internet Sources and websites

Programme Two

Fig	Description	Website reference
2.1	Ship in trouble.	www.sea-room.com
2.2	Captain's cabin.	www.mp-labs.com
2.3	Captain's Log.	www.spminiatures.com/nflogbook.jpg
2.4	Sir Clowdisley Shovell.	www.submerged.co.uk
2.5	Bryher, Isles of Scilly.	www.breakswithtradition.com
2.6	Cezanne: The Hanged Man's House.	www.artchive.com
2.7	Ship on rocks.	www.marinesalvagepi.com
2.8	Two English Ships Wrecked.	www.nmm.ac.uk
2.9	Grave of Rear Admiral Shovell.	www.submerged.co.uk/ association.php
2.10	Gypsy woman.	www.makeup-fx.com
2.11	Ring.	www.bromes.com
2.12	The world's oceans from the South Pole.	www.search.com
2.13	Salvage.	www.badarai.asn.au
2.14	The Earth.	www.astro.washington.edu
2.15	Earth.	www.kowoma.de
2.16	Ship at sea.	www.holyhead.com
2.17	Sailing Ships.	www.neptune.info
2.18	Incense burner.	www.innergifts.com
2.19	Galileo.	www.jrscience.wcp.muohio.edu
2.20	Pisa Cathedral.	www.faculty.valencia.cc.fl.us
2.21	Pisa Cathedral view of apse.	www.si.umich.edu
2.22	Aristotle.	www.faculty.washington.edu
2.23	Cannonball.	www.civilwardealers.com

2.24	Galileo.	www.eo.ucar.edu
2.25	A 16th-century lithograph printing mathematics.	www.wally.rit.edu
2.26	Falling feathers.	www.fotosearch.com
2.27	Galileo.	www.rakemag.com
2.28	Galileo's telescope.	www.esa.int/images/ Galileo_telescope_L.jpg
2.29	The Moon.	www.pa.msu.edu/.../ moon/moon-20day-2845.jpg
2.30	The Moon in colour.	www.nssdc.gsfc.nasa.gov
2.31	Galileo.	www.york.ac.uk
2.32	Galileo's actual drawings.	web.hao.ucar.edu
2.33	Sun showing sunspots.	www.planety.astro.cz
2.34	Saturn's rings.	www.universetoday.com
2.35	Satellites around Jupiter.	www.solarsystem.nasa.gov
2.36	Image: 0 Degrees East Longitude.	www.earthandspace.info
2.37	Jupiter's moons.	www.americandigest.org
2.38	Tables of predictions.	www.npnweb.com
2.39	King Phillip III.	www.eurotravelling.net
2.40	The Canvas of God.	www.agapewebpromotion.com
2.41	Surface of the moon shot from the Spacecraft Apollo 10.	www.nasa.gov
2.42	Horse rider.	www.digitaltoast.co.uk
2.43	Copernicus.	www.academic.brooklyn.cuny.edu
2.44	Monk at work.	www.ccat.sas.upenn.edu
2.45	Sign.	www.codinghorror.com
2.46	Galileo.	www.bemyastrologer.com
2.47	Trial of Galileo Galilei.	www.law.umkc.edu
2.48	Corridors of the Vatican.	www.atwtravel.net
2.49	Italy.	www.cnn.com
2.50	Cardinals.	www.dw-world.de
2.51	Galileo's Problems With the Church.	www.2020site.org
2.52	The Universe of Galileo.	www.muse.tau.ac.il
2.53	Copernican model.	www.vt-2004.org
2.54	Galileo & The Telescope.	www.galileo.rice.edu
2.55	Cover of Galileo's book 'Dialogue on the Great World Systems'.	www.landskrona.astronomy.museum
2.56	Pope Urban VIII 1632.	www.69.20.65.141
2.57	Galileo forced to recant.	www.galileosastronomos.tripod.com
2.58	Descartes.	www.philosophy.umd.edu
2.59	Sweden.	www.europa.eu.int
2.60	Galileo on book cover.	www.voicewin.com
2.61	Sir Isaac Newton.	www.biografiasyvidas.com
2.62	Central Northern Europe.	www.seismo.ethz.ch
2.63	Melaka - replica trading ship.	www.members.virtualtourist.com
2.64	Zaanse Schans Dutch windmill.	www.exploitz.com
2.65	White Cliffs of Dover.	www.dover-web.co.uk
2.66	Oliver Cromwell 1643-1658.	www.newgenevacenter.org
2.67	Plague 1665.	www.learningcurve.gov.uk
2.68	Newton's Woolsthorpe-birthplace.	www.astrosurf.org
2.69	Page from one of Newton's notebooks.	www.nypl.org
2.70	Newton.	www.sprott.physics.wisc.edu
2.71	Newton at 46; Moon at full.	www.ucl.ac.uk

2.72	Newton's rooms Trinity College, Cambridge.	www.research.att.com
2.73	A drawing Isaac Newton made of the prism experiment he conducted in his dorm room in Cambridge.	www-psych.stanford.edu
2.74	Isaac Newton's telescope.	www.museum.vic.gov.au
2.75	Triangular chunk of glass.	www.astrophys-assist.com
2.76	Through a triangular glass prism.	www.library.thinkquest.org
2.77	Light refraction through a prism.	www.seismo.unr.edu
2.78	Refraction through a prism.	www.library.thinkquest.org
2.79	Introduction to the Bases of Colour.	www.psych.ucalgary.ca
2.80	Robert Hooke.	www.vitruvio.imss.fi.it
2.81	Isaac Newton at his desk.	www.linux-magazin.de
2.82	Isaac Newton.	www.historyguide.org
2.83	Isaac Newton.	www.pbs.org
2.84	The clockwork universe.	www.physicalworld.org
2.85	Newton's statue at Cambridge.	www.cambridge2000.com
2.86	Gottfried Wilhelm Leibniz.	www.lacentral.com
2.87	Sir Isaac Newton.	www.lucidcafe.com
2.88	Edmund Halley.	www.nationalarchives.gov.uk
2.89	Edmund Halley.	www.astrosurf.org
2.90	Newton's Principia.	www.en.wikipedia.org
2.91	Newton's cradle.	www.colorado.edu
2.92	Newton's Cradle desk toy.	www.electix.nl
2.93	Outer space.	www.jiskha.com
2.94	Isaac Newton.	www.biografiasyvidas.com
2.95	Palace of Westminster.	www.explore.parliament.uk
2.96	Isaac Newton.	www.telosnet.com
2.97	ngc281FRGB01web.	www.heavensgloryobservatory.com
2.98	The Longitude Act.	www.arte-tv.com
2.99	Money falling from the sky.	www.fotosearch.de
2.100	Ocean.	www.web.media.mit.edu
2.101	One nautical-mile ahead.	www.tgw.net
2.102	Board of Longitude.	www.image.sl.nsw.gov.au
2.103	Model ship.	www.hobbyplace.com
2.104	Newton.	www.sprott.physics.wisc.edu
2.105	House Plaque.	www.answers.com/topic/john-harrison
2.106	Trinity Church Barrow-upon-Humber.	www.uktouristinfo.com
2.107	Wooden products.	www.smithstuff.net
2.108	Antiquated, antique book.	www.istockphoto.com
2.109	Wooden clock details.	www.clockmaker.it
2.110	John Harrison's first clock H 1.	www.voanews.com/specialenglish/images/esa/int_clock
2.111	The Cutty Sark.	www.ageofsail.net/images/004-03
2.112	Sketch of Brocklesby Park Stable Block showing Harison's clock.	www.homepage.ntlworld.com
2.113	Edmund Halley.	www.atschool.eduweb.co.uk
2.114	George Graham.	www.scienceandsociety.co.uk
2.115	H1 c Harvard College Press.	www.inference.phy.cam.ac.uk
2.116	John Harrison's H1.	www.24hourmuseum.org.uk
2.117	John Harrison's H4 Chronometer.	www.24hourmuseum.org.uk
2.118	Berne, Switzerland.	www.jefflewis.net

2.119	Albert Einstein 1879-1955.	www.ethbib.ethz.ch
2.120	Berne clock tower.	www.pbs.org
2.121	The clock that Einstein looked at.	www.ironic.com
2.122	Einstein Pocket Watch.	www.oddbox.com
2.123	Einstein relativity and time.	www.npl.co.uk
2.124	Creating ripples in a pond.	www.utexas.edu
2.125	Big-Ben.	www.londongeneral.co.uk
2.126	The Greenwich Meridian Line.	www.portcities.org.uk
2.127	Isaac Newton.	www.eia.doe.gov
2.128	Albert Einstein.	www.biografiasyvidas.com
2.129	Albert Einstein.	www.mediatheek.thinkquest.nl
2.130	Einstein.	www.twoday.net
2.131	Universe.	www.samueljscott.wordpress.com
2.132	Mathematics.	www.jiskha.com
2.133	Concorde.	www.ciel.me.cmu.edu
2.134	Telescopes.	www.ulo.ucl.ac.uk

Programme Three

Sources Consulted

1 Singh S. 1999 *The Code Book,* Reed, London.

Internet Sources and websites

1 The Enigma cipher machine, http://www.codesandciphers.org.uk/enigma/, accessed on 18/06/06.

2 The Alan Turing Internet Scrapbook, Critical Cryptanalysis: The Enigma War, 1939-1942. http://www.turing.org.uk/turing/scrapbook/ww2.html, accessed on 18/06/06.

3 Bletchely Park National Codes Centre, http://www.bletchleypark.org.uk/, accessed on 18/06/06.

4 Enigma: an enigma simulator site, http://www.xat.nl/enigma/, accessed on 18/06/06.

5 Nova online: How the Enigma Works, http://www.pbs.org/wgbh/nova/decoding/enigma.html, accessed on 18/06/06.

6 About Enigma and Its Decryption, http://homepages.tesco.net/~andycarlson/enigma/about_enigma.html, accessed on 18/06/06.

7 Captured U-boats, http://uboat.net/fates/captured.htm, accessed on 19/06/06.

8 Hitler's Enigma, http://www.lawbuzz.com/tyranny/u571/u571_ch4.htm, accessed on 19/06/06.

9 The Secret of the U-110, http://www.ihffilm.com/r543.html, accessed on 19/06/06.

Illustrations

Internet Sources and websites

Programme Three

Fig	Description	Website reference
3.1	Mary Queen of Scots.	www.lawcastle.com
3.2	The Crown Jewels.	www.geocities.com
3.3	Sir Francis Walsingham.	www.tudorplace.com.ar
3.4	Dr. John Dee.	www.hants.org.uk
3.5	Sir Francis Walsingham 1532-90.	www.history.wisc.edu
3.6	Queen Elizabeth I.	www.marileecody.com
3.7	Mary Queen of Scots.	www.maybole.org
3.8	Code used by Mary Queen of Scots.	www.sevenhills.leeds.sch.uk
3.9	Historical Maps of Europe.	www.lib.utexas.edu
3.10	Herodotus, The Father of History.	www.etsu.edu
3.11	Ancient Greece.	www.shunya.net
3.12	Secret Writing.	www.jcooperstudio.com
3.13	Chartley Hall and Grounds.	www.search.staffspasttrack.org.uk
3.14	Mary, Queen of Scots.	www.pbs.org
3.15	Beer Barrel South Bend.	www.coleauctionsinc.com
3.16	Wooden barrel.	www.trainstuffllc.com
3.17	Francis Walsingham.	www.tudorplace.com.ar
3.18	Elizabethan Accessories.	www.heatherspages.net
3.19	Anthony Babington.	www.lawbuzz.com
3.20	Ruins of Wingfield Manor, Peak District, England. Location where Babington plotted to free Mary Queen of Scots.	www.timetravel-britain.com
3.21	Tavern Scene.	www.gallery.euroweb.hu
3.22	Letter signed by Mary Queen of Scots.	www.sheffieldmarkets.co.uk
3.23	Beer-Barrel.	www.gutenberg.org
3.24	Message used in the Babington Plot.	www.en.wikipedia.org
3.25	Sir Francis Walsingham.	www.pbs.org
3.26	English Alphabet.	www.roslin.com
3.27	Francis Walsingham.	www.tudorplace.com.ar
3.28	Playing spy with easy codes.	www.eleves.ens.fr
3.29	The actor Geoffrey Rush as Sir Francis Walsingham.	www.aboutjamesfrain.com
3.30	Sir Francis Walsingham.	www.guildofstgeorge.com
3.31	Courthouse & hangman's scaffold.	www.tropicalvegas.com
3.32	Film of The Execution of Mary Queen of Scots made by Alfred Clark of the Edison Kinestoscope Company believed to be the first movie special effect. The execution of Mary Queen of Scots.	www.pbs.org
3.33	Medieval Executioner's Axe.	www.ricksswords.com
3.34	NATO.	www.global-defence.com
3.35	Samuel Morse.	www.biografieonline.it
3.36	Telegraph pole.	www.abc.net.au
3.37	War-time Diaries.	www.fas-history.rutgers.edu
3.38	Wireless Telegraphy.	www.spartacus.schoolnet.co.uk

3.39	4270 early German Luftwaffe Wireless.	www.w1tp.com
3.40	The White House.	www.dblell.com
3.41	A single-rotor Hebern machine.	www.en.wikipedia.org
3.42	Oosteinde Delft watercolour.	www.enidlawsongallery.co.uk
3.43	Enigma machine stolen from Bletchley Park in 2000.	www.frode.home.cern.ch
3.44	One of the first Trade Fairs.	www.angabisuteria.com
3.45	German Post Office.	www.hh.schule.de
3.46	Sturmabteilung SA Brownshirts.	www.members.aol.com
3.47	Erich Fellgiebel.	www.swr.de
3.48	Cipher machines: The German Enigma.	www.w1tp.com
3.49	Poland Map.	www.travel.yahoo.com
3.50	Poland, coat of arms.	www.civicheraldry.com
3.51	German soldiers using an Enigma Machine during the Second World War.	http://plus.maths.org/issue34/features/ellis/
3.52	Crate.	www.indygear.com
3.53	Enigma-rotors.	www.ilord.com
3.54	The Gate in University of Gottigen.	www.princeton.edu
3.55	Cipher machines The German Enigma.	www.w1tp.com
3.56	Gustave Bertrand.	www.militarni.pl
3.57	An Enigma codebook recovered from the captured U-505.	www.answers.com
3.58	An Early Enigma Model B.	www.armyradio.com
3.59	Hitler.	www.what-means.com
3.6	Marian Rejewski.	www.answers.com
3.61	Invasion of Poland Sept 1939.	www.cla.calpoly.edu
3.62	Bletchley Park.	www.smithstuff.net
3.63	Alan Turing.	www.fusionanomaly.net
3.64	The Enigma War.	www.25.brinkster.com
3.65	June 3, 1940 - Evacuation of Dunkirk.	www.historyplace.com
3.66	Huts 3 and 6 at Bletchley Park.	www.faculty.goucher.edu
3.67	Bletchley staff.	www.qsl.net
3.68	10 May 1940 33 Allied aircraft attack German positions.	www.raf.mod.uk/bombercommand
3.69	German troops march toward the Arc de Triumphe.	www.ucc.uconn.edu
3.7	QWERTY Keypad.	www.dca.ca.gov
3.71	German Enigma machine.	www.home.comcast.net
3.72	Bletchley Park.	www.unimelb.ieeevic.org
3.73	The Enigma plug board.	www.nku.edu
3.74	The German Enigma.	www.w1tp.com
3.75	Alan Turing in the Garden.	www.f.home.cern.ch
3.76	The Turing Bombe.	www.ellsbury.com
3.77	Bombe wiring (A rebuild of Turing's bombe).	www.gallery.spacebar.org
3.78	Enigma.	www.usaaf.net
3.79	Battle of the Atlantic.	www.ahoy.tk-jk.net
3.8	A mock-up of Turing's Bombe.	www.exaro.co.uk
3.81	Turing's Bombe machines.	www.compshopper.co.uk
3.82	Bust of Churchill at Bletchley Park.	www.crowell.co.uk
3.83	Turing.	www.rom.gr
3.84	Gayhurst Manor.	www.mkheritage.co.uk
3.85	North Africa.	www.fefemissions.com
3.86	Junkers Ju88, German Luftwaffe.	www.lonesentry.com
3.87	Ian Fleming.	www.home.comcast.net

3.88	Ian Fleming and ornithologist James Bond.	www.ajb007.co.uk
3.89	German ships.	www.spartacus.schoolnet.co.uk
3.90	U110 German U-Boat with German naval rating using Enigma. This was the machine captured by British Forces.	www.mikekemble.com
3.91	HMS Bulldog H 91 seen here before World War II.	www.uboat.net
3.92	Lemp seen here on U-30, his previous command before U-110.	www.mikekemble.com
3.93	Boarding party heading for U-110 sub from HMS Bulldog.	www.mikekemble.com
3.94	Kapitänleutnant Fritz-Julius Lemp after receiving his Knights Cross.	www.uboat.net
3.95	Lieutenant David Balme.	www.news.bbc.co.uk
3.96	Map of Iceland.	www.scantours.com
3.97	U-Boat attack just before bombs away. Shot from a Catalina.	www.navylib.com
3.98	Kurt Fricke Commander-in-Chief of the German Navy.	www.feldgrau.com
3.99	Purple Japanese cipher machine.	www.mccullagh.org
3.100	Philip Johnston.	www.signonsandiego.com
3.101	The Navajo Indian Code-Breakers.	www.nau.edu
3.102	Hitler.	www.upload.wikimedia.org
3.103	Working at Bletchley.	www.ilord.com
3.104	The Lorenz Cipher Machine. It was the most advanced encryption machine the Germans made.	www.rubycon.org
3.105	The Lorenz Machine.	www.alanturing.net/.../ LorenzPhoto.html
3.106	Max Newman.	www.fc.up.pt
3.107	Bletchley Park.	www.en.wikipedia.org
3.108	Tommy Flowers.	www.connected-earth.com/
3.109	Dollis Hill.	www.cowfish.org.uk
3.110	Tommy Flowers on rhs.	www.virtualmuseum.dlib.vt.edu
3.111	A Picture of The Colossus Computer.	www.people.bath.ac.uk
3.112	The rebuilt Colossus now on show at Bletchley Park.	www.angelfire.com
3.113	HRH Duke of Kent.	www.churchill-society-london.org.uk/
3.114	Secrecy soviet union.	www.fas.org www.cheguevara.itgo.com
3.115	The ENIAC.	www.photo2.si.edu
3.116	Photograph of John W. Mauchly, ca. 1940-50.	www.library.upenn.edu
3.117	John Presper Eckert.	www-groups.dcs.st-and ac.uk
3.118	GCHQ aka the doughnut, Cheltenham.	www.designbuild-network.com/
3.119	US National Code Talkers Day.	www.theguys.org
3.120	Ultra Secret.	www.bookweb.kinokuniya.co.jp
3.121	Internet.	www.fraunhofer.de
3.122	Real Digital Signal.	www.people.deas.harvard.edu
3.123	Bob and Alice.	www.math.cornell.edu
3.124	Key.	www.medicalarchives.jhmi.edu
3.125	Online Security.	www.naa.gov.au
3.126	Sending Messages.	www.humsci.auburn.edu
3.127	Bob and Alic.e	www.arx.com
3.128	Alice, Bob, Alice.	www.microsoft.com
3.129	British Bobby helmet.	www.sieglers.com

Programme Four

Sources Consulted

1 Burke J.1978 *Connections,* Macmillan: London.

2 Hogben L.1938 *Mathematics for the Million,* Unwin: London.

3 Singh S. 1997 *Fermat's Last Theorem,* Fourth Estate: London.

Internet Sources and websites

1 Apollo 13, http://www.math.iupui.edu/m261vis/A-13.html , accessed on 20/06/07.

2 Apollo 13: A Successful Failure,
http://liftoff.msfc.nasa.gov/Academy/History/APOLLO-13/mission-report.html.
Excerpted from W. David Compton, Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions (Washington, D.C.: NASA SP-4214, 1989), pp. 386-93. accessed on 20/06/07.

3 What really happened to Apollo 13,
http://www.ghg.net/woodfill/TRACT13.html accessed on 20/06/07.

4 Catalogue Niccolò Tartaglia, http://www.mhs.ox.ac.uk/geometry/cat1.htm, accessed on 20/06/07.

5 The MacTutor History of Mathematics archive,
http://www-history.mcs.st-and.ac.uk/, accessed on 20/06/07.

6 Institute and Museum of the history of science,
http://www.imss.firenze.it/, accessed on 20/06/07.

7 Rockets in World War II,
http://www.allstar.fiu.edu/aero/rock3.htm, accessed on 20/06/07.

8 Peenemunde – 1943, http://www.globalsecurity.org/wmd/ops/peenemunde.htm, accessed on 20/06/07.

NB re Programme four Sc 129

[The cryogenic hydrogen tanks are stirred by internal fans to homogenise their density. The cryogen, when in the tank, has been described as a very 'dense fog' rather than a liquid; in zero G it tended to separate into layers of different densities around the quantity gauging system's capacitive probe creating a false quantity reading. The two small fans were used to periodically (once/day) stir up the cryogen (H2 or O2) to make it homogenous and allow the capacitive probe to produce an accurate signal/reading.]

Illustrations

Internet Sources and websites

Programme Four

Fig	Description	Website reference
4.1	Map of the Length of the Nile.	www.specialtyinterests.net
4.2	Geometry.	www.csupomona.edu
4.3	Geometry symbolism in Egyptian culture.	www.constructingtheuniverse.com
4.4	The River Nile.	www.titherly.com
4.5	Priests of Ancient Egypt.	www.touregypt.net
4.6	Priests Egypt.	www.maa.missouri.edu
4.7	Greeks in Egypt 0 to 500 BC.	www.suziemanley.com
4.8	Flooding along the Nile River.	www.eosweb.larc.nasa.gov
4.9	Flooding along the White Nile.	www.gesource.ac.uk
4.10	Great Pyramids of Egypt.	www.mathsisfun.com
4.11	Thales.	www.tpaweb.org
4.12	The Great Pyramid.	www.europa.com
4.13	Cities.	www.coe.west.asu.edu
4.14	Arrow slit reveals.	www.campbellholt.com
4.15	Conics.	Author produced image
4.16	Measuring a pyramid.	Author produced image
4.17	Stating the problem.	Author produced image
4.18	Setting up the equation.	Author produced image
4.19	Re-arranging the equation.	Author produced image
4.20	Setting up the equation.	Author produced image
4.21	Caravan Crossing the Desert.	www.rehsgalleries.com
4.22	Trade routes to the Red Sea.	www.egyptorigins.com
4.23	Euclid.	www.hometown.aol.com
4.24	Euclid's Elements.	www.rsl.ox.ac.uk
4.25	Pythagoras.	www.epsilones.com
4.26	Samos Island.	www.samos.gr
4.27	Pythagoras.	www.did.mat.uni-bayreuth.de
4.28	Chicago Harpist Courtney Lawhn.	www.chicago-harpist.com
4.29	Member of Harpist Yorkshire.	www.harpist-yorkshire.co.uk
4.30	Harmony.	www.elfwood.lysator.liu.se
4.31	Pythagoras.	www.astrologycom.com
4.32	Natural vegetation.	www.coastalguide.org
4.33	Horizon Sunset.	www.canvasartprints.com
4.34	Revolution.	Author produced image
4.35	Map of Samos.	www.pithagorio.net
4.36	Pythagoras theorem.	www.xperiment.se
4.37	Theorem of Pythagoras.	Author produced image
4.38	Pythagorean Triple.	Author produced image
4.39	Triangles in three-dimensional space.	www.math.tamu.edu
4.40	Fermat à Beaumont de Lomagne, Fermat's Birthplace.	www.home.nordnet.fr
4.41	Pierre de Fermat.	www.fr.wikipedia.org
4.42	Pierre de Fermat.	www.mathematik.ch
4.43	Beaumont de Lomagne début XX° siècle.	www.bastidess.free.fr
4.44	Pierre de Fermat 1601-1665.	www.microscopy.fsu.edu
4.45	Manfred Boergens - Satz von	www.fh-friedberg.de

	Fermat.Czech republic stamp showing Fermat's Last Theorem.	
4.46	Holographic will handwritten by Pierre de Fermat on March 4, 1660 – Kept at the Departmental Archives of Haute-Garonne, in Toulouse.	www.en.wikipedia.org
4.47	Page from Diophantus Arithmetica.	www.boston-arts-academy.org
4.48	Pierre de Fermat.	www.edinformatics.com
4.49	Fermat's Last Theorem.	www.emsh.calarts.edu
4.50	Pythagorean Triple.	Author produced image
4.51	Fermat's Last Theorem.	www.uwe.ac.uk
4.52	Algebraic Pythagorean Triple.	Author produced image
4.53	Fermat in algebra 1.	Author produced image
4.54	Fermat's Last Theorem.	www.math.utah.edu
4.55	Doughnuts and Fermat last theorem.	www.staff.science.uva.nl
4.56	Fermat's Last Theorem.	www.libreriauniversitaria.it
4.57	Child's building blocks.	www.inmagine.com
4.58	Fermat's last theorem.	www.pennsvalley.org
4.59	Crying baby.	www.ehp.niehs.nih.gov
4.6	Andrew Wiles at the age of 10.	www.simonsingh.com
4.61	Andrew Wiles.	www.lahabra.seniorhigh.net
4.62	From riddles. Solving an equation.	www.tcnj.edu
4.63	Andrew Wiles.	www.nndb.com
4.64	The campus of Princeton University.	www2.physics.umd.edu
4.65	Falling papers.	www.stephanieburns.com
4.66	Complex Analysis.	www.facweb.stvincent.edu
4.67	Andrew Wiles.	www.uvm.edu
4.68	Emails being sent.	Author produced image
4.69	Staff Rooms.	www.dpsrkp.net
4.70	Prof Andrew Wiles.	www.shawprize.org/img/ prize/2005/AndrewWiles.
4.71	Andrew Wiles.	www.ams.org
4.72	A student's attempt to prove Fermat's Last Theorem.	www.elithic.com
4.73	Cambridge.	www.davidmetraux.com
4.74	Princeton University.	www.benbolger.com
4.75	Professor Peter Sarnak.	www.lehigh.edu
4.76	Richard Taylor.	www.encycl.opentopia.com
4.77	Passing time.	www.osiris.rutgers.edu
4.78	Maze.	www.slimeland.com
4.79	Noam Elkies.	www.claymath.org
4.80	Pictures of mathematics.	www.cs.utsa.edu
4.81	Harvard University.	www.web.mit.edu
4.82	Yutaka Taniyama. The Taniyama-Shimura Conjecture.	www.people.bath.ac.uk
4.83	Taniyama-Shimura conjecture.	www.geocities.com
4.84	Emails.	www.kitetoa.com
4.85	Henri Darmon.	www.modular.fas.harvard.edu
4.86	Princeton University in Summer.	www.img.photobucket.com
4.87	Andrew Wiles.	www.elib.zib.de
4.88	Andrew Wiles.	www.sylvianickerson.ca
4.89	Pierre de Fermat.	www.edinformatics.com
4.90	Closing door opens a new door.	www.thisfunsforyou.com
4.91	Marin Mersenne.	www.ko.wikipedia.org
4.92	Flies.	www.washington.edu
4.93	Cartesian coordinates.	www.openstages.com
4.94	Graph of $y = x$.	www.gcse.com
4.95	Analytical Geometry.	www.khs-kappeln.lernnetz.de

4.96	Graphs - Polynomial Equations.	www.bbc.co.uk
4.97	Cannonball trajectory.	www.physicsclassroom.com
4.98	Cannonball trajectory with graph.	www.physicsclassroom.com
4.99	Castles in Wales.	www.walesdirectory.co.uk
4.100	Castle showing the crenellations.	www.secretshropshire.org.uk
4.101	The Round Tower, Windsor Castle.	www.artoftheprint.com
4.102	The round tower.	www.castellitoscani.com
4.103	A Star Fort.	www.answers.com
4.104	Firing a cannon.	www.jwoolfden.com
4.105	Cannons.	www.kestan.com
4.106	Old cannons.	www.istockphoto.com
4.107	Niccolò Tartaglia, the 'stammerer'.	www.mhs.ox.ac.uk
4.108	First page of a book by Tartaglia, explaining Pascal's triangle.	www. softmath.com
4.109	Niccolo Fontana Tartaglia.	www.cimm.ucr.ac.cr
4.110	The use of the gunner's quadrant explained.	http://www.mhs.ox.ac.uk/geometry/fig11n.htm
4.111	A genuine 17th Century quadrant.	http://brunelleschi.imss.fi.it/museum/esim.asp?c=401089
4.112	Hipparchus.	http://www-history.mcs.st-andrews.ac.uk/Biographies/Hipparchus.html
4.113	Hipparchus as a young man.	http://www-history.mcs.st-andrews.ac.uk/Biographies/Hipparchus.html
4.114	Right - angled triangle.	Author produced image
4.115	Hipparchus on a stamp	http://www-history.mcs.st-andrews.ac.uk/PictDisplay/Hipparchus.html
4.116	Right - angled triangle.	Author produced image
4.117	Triangulation.	http://en.wikipedia.org/wiki/Triangulation
4.118	The First ever map of Everest.	www.unlockingthearchives.rgs.org
4.119	Using triangles to fly rockets.	www.library.thinkquest.org
4.120	Corsair fighter looses its load of rocket projectiles on a run against a Japanese stronghold on Okinawa.." Lt. David D. Duncan, ca. 1945. (NARA 127-GR-97-126420).	http://www.allstar.fiu.edu/aero/rock3.htm
4.121	Life in London during the war. View of a V-1 rocket in flight, ca. 1944. (NARA 306-NT-3157V).	http://www.allstar.fiu.edu/aero/rock3.htm
4.122	A V-2 (A-4) on a test stand at Peenemunde, Germany.	http://www.allstar.fiu.edu/aero/rock3.htm
4.123	Dr Wernher von Braun, rocket Scientist.	www.worldroots.com
4.124	Wernher von Braun stands at his desk in the Marshall Space Flight Center,Huntsville, Alabama in May 1964, with models of rockets developed and in progress.	http://en.wikipedia.org/wiki/
4.125	April 11, 1970 - Apollo 13 launch.	www.historyplace.com
4.126	Transcript of the conversation that led to the explosion aboard Apollo 13.	WWW.myweb.accessus.net/~090/as13/as13mocr.jpg
4.127	The damage to Apollo 13.	www.daviddarling.info/.../A/Apollo_13.html
4.128	Apollo 13.	www.nasa.gov
4.129	Moon photographed by Apollo 13.	www.observe.arc.nasa.gov
4.130	Circling Moon.	www.ksc.nasa.gov
4.131	Apollo 13 and vector calculus.	http://www.math.iupui.edu/m261vis/A-13.html
4.132	Apollo 13 control. Panel.	www.answers.com
4.133	Model of Apollo 13 damage.	www.ninfinger.org
4.134	Apollo 13 astronauts setting up CO_2 filter.	www.lpi.usra.edu
4.135	Apollo 13 LiOH filter.	www.space1.com
4.136	re-entry problem 1.	www.ghg.net
4.137	A picture of Apollo 13 re-entry.	www.history.nasa.gov

4.138	The Unity of the Sun, Earth and Moon.	www.livingcosmos.com
4.139	The Earth's terminator.	www.cseligman.com
4.140	Fractal Art Wallpaper.	www.abm-enterprises.net
4.141	Triangles of Light.	www.trianglesoflight.org
4.142	Rene Descartes.	www.daviddarling.info
4.143	Fermat, Pierre de 1601-1665.	www.york.ac.uk
4.144	Andrew Wiles.	www.library.thinkquest.org
4.145	Nile River.	www.library.thinkquest.org
4.146	Crew Apollo 13.	www.spacefacts.de
4.147	Earth.	www.harmsy.freeuk.com

Programme Five

Sources Consulted

1. Hogben L. 1938 *Mathematics for the Million,* Unwin: London.

2. Burke J.1985 *The Day the Universe Changed,* BBC: London.

Internet Sources and websites

1 Materials for the History of Statistics, http://www.york.ac.uk/depts/maths/histstat/, accessed 25/06/07.

2 History of Statistics and Probability, http://www.mrs.umn.edu/~sungurea/introstat/history/indexhistory.shtml, accessed 25/06/07.

3 Figures from the History of Probability and Statistics, http://www.economics.soton.ac.uk/staff/aldrich/Figures.htm, accessed 25/06/07.

4 A short History of Probability and Statistics, http://www.leidenuniv.nl/fsw/verduin/stathist/stathist.htm, accessed 25/06/07.

5 A Short History of Probability, http://www-static.cc.gatech.edu/classes/cs6751_97_winter/Topics/stat-meas/probHist.html, accessed 25/06/07.

Illustrations

Internet Sources and websites

Programme Five

Fig	Description	Website reference
5.1	Medieval ship replica, Genoa.	www.italianvisits.com
5.2	Card Games	www.geocities.com
5.3	Sir Nicholas Bacon.	www.tudorplace.com.ar
5.4	Medieval Fleet.	www.dsm.de
5.5	Medieval Society.	www.english.boisestate.edu
5.6	FERMAT, Pierre de 1601-1665.	www.york.ac.uk
5.7	Blaise Pascal.	www.utilitarianism.com
5.8	Tudor Dice.	www.creativehistory.co.uk
5.9	Royal and Britannia in Battle, 1693.	www.jamesaflood.com
5.10	Sir Nicholas Bacon.	www.tudorplace.com.ar
5.11	Pastimes in Tudor England.	www.hullwebs.co.uk
5.12	Historical Maps of Europe.	www.lib.utexas.edu
5.13	Architecture in Belgium: Antwerp.	www.bc.edu
5.14	Nobles 16th Century.	www.accentonrugs.com
5.15	Medieval Fair.	www.mirfin.ru
5.16	Villalón.	www.flg.es

5.17	Baby Boy.	www.peterrobertojr.com
5.18	Antwerp merchants.	www.hollstein.com
5.19	Probability and Statistics.	www.ima.umn.edu
5.20	London financiers.	www.trytel.com
5.21	Horse Racing.	www.nytimes.com
5.22	Tossing A Coin Cartoons.	www.cartoonstock.com
5.23	Tossing A Coin.	www.dreamstime.com
5.24	2006 Gold 4 Coin Set.	www.taxfreegold.co.uk
5.25	Chance of the Duckling catching the fly.	www.aura.zaadz.com
5.26	The First Sunrise of The Year.	www.city.choshi.chiba.jp
5.27	Nighttime at the beach.	www.drewnoakes.com
5.28	There are really impossible things.	www.cut-the-knot.org
5.29	Probability Line.	Author produced image
5.30	Probability of impossibility.	Author produced image
5.31	Probability of certainty.	Author produced image
5.32	Risk.	www.wisdomofthecrone.com
5.33	Risk-Cliff Jumper.	www.riroads.com
5.34	Lucky 7.	www.olemiss.edu
5.35	Sample space.	Author produced image
5.36	Horseracing.	www.richardsons-group.co.uk
5.37	Greyhound Racing.	www.dog-track.co.uk
5.38	UK Politics | Overhaul.	www.news.bbc.co.uk
5.39	Ecological risk assessment.	www.gradst.hr
5.40	Medieval European trade routes.	www.trade-routes-resources.blogspot.com
5.41	Historical earthquake data.	www.seismo.ethz.ch
5.42	Modern Early Europe | All Empires.	www.allempires.com
5.43	Simple mathematical rules.	www.casinoonnet.sk
5.44	Jean Domat 1625-1696.	www.academic.brooklyn.cuny.edu
5.45	Lottery Logo.	www.national-**lottery**.co.**uk**
5.46	Christiaan Huygens 1629-1695.	www.20eeuwennederland.nl
5.47	Johan de Witt , 1625-1672.	www.geerts.com
5.48	Christiaan Huygens.	www.astro.if.ufrgs.br
5.49	Huygens.	www.photonics.usask.ca
5.50	Game theory.	www.gametheory.net
5.51	FDe WITT, Jan 1625-1672.	www.york.ac.uk
5.52	An Early law court.	www.aliciapatterson.org
5.53	The Measurers.	www.mhs.ox.ac.uk/measurer/images/fig4s.gif
5.54	Llandudno Catholic Church.	www.llandudno-catholic-church.org.uk
5.55	Ars Conjectandi page.	www.nsm1.nsm.iup.edu
5.56	Jacob Bernoulli .	www.umass.edu
5.57	Dice.	www.prevezanos.com
5.58	Nature.	www.goodfelloweb.com
5.59	Jacob Bernoulli.	www.isi.cbs.nl
5.60	Origins of Human Behaviour.	www.bbc.co.uk
5.61	Mathematics and Theology in Raphael's paintings.	www.nexusjournal.com
5.62	Painting called The Rationality of Paradise.	www.acquaye.de
5.63	Pascal's Wager.	www.kingofpeace.blogspot.com
5.64	Blaise Pascal.	www.fr.wikipedia.org
5.65	John Tillotson, Archbishop of Canterbury.	www.pibburns.com
5.66	Clapham common bus circa 1950.	http://landmark.lambeth.gov.uk/siteimages/pic05/fullsize/04824
5.67	Philosophical Essay on Probabilities.	www.amazon.com
5.68	Pierre-Simon marquis de Laplace.	www.eadshome.com
5.69	Mathematical Theory of Probability.	www.math.ou.edu
5.70	Tossing Coins Cartoons.	www.cartoonstock.com

5.71	Imperial Academy of Sciences.	www.en.wikipedia.org
5.72	Daniel Bernoulli.	www.plus.maths.org
5.73	Bernoulli, Daniel 1700-1782.	www.york.ac.uk
5.74	Changing human behaviour.	www.weblog.leidenuniv.nl
5.75	Jean d Alembert.	www.resonancepub.com
5.76	D Alembert.	www.restode.cfwb.be
5.77	Mock-up of smallpox victim.	www.news.bbc.co.uk
5.78	Paris 1721-1750.	www.brown.edu
5.79	Daniel Bernoulli.	www.mathematik.ch
5.80	Jean D'Alembert (1753).	www.axonais.com
5.81	A map of life-expectancies.	www.egge.net
5.82	Jean Le Rond D Alembert.	www.membres.lycos.fr
5.83	Georges-Louis Leclerc De Buffon.	www.answers.com
5.84	Condorcet.	www.arelc.org
5.85	Laplace.	www.geocities.com
5.86	Any reasonable person.	www.buddycom.com
5.87	Enlightenment.	www.oup.com
5.88	Crowd of people.	www.ljmu.ac.uk
5.89	Official Records.	www.dundeecity.gov.uk
5.90	The Nation State & Human Rights.	www.academic.brooklyn.cuny.edu
5.91	Statistics - Literacy 2000.	www.uis.unesco.org
5.92	Graunt, John 1620-1674.	www.york.ac.uk
5.93	John Graunt: extracts from his book.	www.oohara.mt.tama.hosei.ac.jp
5.94	Life Expectancy on the Rise.	www.blog.speculist.com
5.95	Petty, Sir William 1623-1687.	www.york.ac.uk
5.96	Life expectancies by age.	www.euroreves.ined.fr
5.97	Libby Prison Insurance Policy, 1864.	www.mdgorman.com
5.98	Lottery.	www.tradingstandards.gov.uk
5.99	Numerologists.	www.newage-kabbalah-numerology.com
5.100	Gambling.	www.mooddisorderscanada.ca
5.101	17th Century.	www.columbia.edu
5.102	Lotteries.	www.gamblingcommission.gov.uk
5.103	Life insurance.	www.britishassurance.com
5.104	18th century cards and playing chips.	www.math.utep.edu
5.105	Death.	www.oz.irtc.org
5.106	Death Portrait Head.	www.paulkidby.com
5.107	Election of James Dodson to Royal Society 1757.	www.royalsoc.ac.uk
5.108	The Privy Council.	www.history.wisc.edu
5.109	Life Insurance.	www.investorslife.com
5.110	Risk - an added vital ingredient.	www.sutcliffeplay.co.uk
5.111	Enlightenment.	www.oup.com
5.112	Siméon Poisson.	www-history.mcs.st-andrews.ac.uk
5.113	Large populations of sea birds.	www.photolib.noaa.gov
5.114	Death Scene II – 1.	www.mai.mercyhurst.edu
5.115	Un-sequenced human life cycle page.	www.btc.montana.edu
5.116	Criminal at Large.	www.criminal-management.co.uk
5.117	Intelligent-design.	www.people.howstuffworks.com
5.118	19th Century Education.	www.oceanspringsarchives.com
5.119	19th century.	www.passmoresschool.com
5.120	Pierre-Simon, Marquis de Laplace.	www.mlahanas.de
5.121	Average.	www.billmon.org
5.122	Adolphe Quetelet.	www-history.mcs.st-and.ac.uk
5.123	Quetelet.	www.jeff560.tripod.com
5.124	Adolphe Quetelet.	www.swlearning.com
5.125	Average British man: 74 kilograms.	www.thinkmetric.org.uk
5.126	Francis Galton.	www.swlearning.com

5.127	Extract from Dalton's notebook.	http://galton.org/statistician.html
5.128	Galton.	www1.umn.edu
5.129	Galton aged 87, with Karl Pearson.	www.galton.org
5.130	Albert Einstein.	www.hep.fi.infn.it
5.131	Spearman, Charles Edward 1863-1945.	www.york.ac.uk
5.132	Sir Francis Galton.	www.huxley.net
5.133	Francis Galton's book.	www.allbookstores.com
5.134	Standard deviation formula.	www.coe.sdsu.edu
5.135	Galton.	www.bun.kyoto-u.ac.jp
5.136	Galton.	www.mat.usal.es
5.137	Global warming.	www.newsfromrussia.com
5.138	Global temperatures.	www.en.wikipedia.org/wiki/**Global_warming**
5.139	Rising global temperatures.	en.wikipedia.org/wiki/Global_warming
5.140	The Greenhouse Effect.	http://en.wikipedia.org/wiki/Greenhouse_effect
5.141	Central-England-Temperatures.	www.zfacts.com
5.142	Global Warming.	www.techpolicy.typepad.com
5.143	Stats and facts – UK.	www.mediaspace.aol.co.uk
5.144	Lancelot Hogben.	www.raunvis.hi.is

Appendix 1 Narratology

In writing the creative work for this thesis I have consciously used a set of values for the narration. The purpose of this appendix is to sketch in something of my approach to the writing of the narration.

The Purpose of Narration

The purpose of narration in the documentary is threefold:

- to establish the documentary by starting the viewer off with the necessary prior knowledge
- to help the story take temporal and locational leaps as the narrative unfolds
- to bring the viewer back to the real world.

(Paget 1998: 68)

This is why I started Programme One with the teasers that ask the viewer to link what appear to be disparate objects. This encourages the viewer to take an active role in the programme as he/she actively re-constructs the scenes to determine meaning from them (Seymour Chatman in Wartenberg and Curran 2005:192). This re-construction of events is analogous to what we now understand in education in terms of how children learn and thus it is not unreasonable to state that the same or similar process is under way here. We do need to be clear what is meant by re-construction. This term is also used in the re-construction of scenes within documentary in such programmes as BBC TV's *Crimewatch*. Here the term refers to the cognitive process whereby the viewer actively constructs their representation of reality and accepts or rejects what is being shown to them via the television screen. This is the televisual form of Rennie and McClafferty's science centres, where the primary objective is to have fun (L. Rennie and T.McClafferty in Scanlon, Whitelegg and Yates1999:79)

This then leads the narration on to my presence in one scene. The purpose of my presence in this scene is to establish the 'authority' of the documentary as a solid piece of authorial reportage (Kilborn 2003:117-8). This is diegetic role in the sense that Derek Paget suggests, namely that it is a method of narration employed in a film and is used to mark the degree to which necessary information is conveyed to an audience from within the world of the film story (Paget 1998:68). The subsequent narration is by voice-over. I did write the first draft with a lot more interaction in the same way that Peter Ackroyd interacted with his characters in *Peter Ackroyd's London* (2004), where he walked down streets inhabited by characters from Victorian times. My problem with this is that it can lead to a false construction of the chronology of events. Derek Paget points out that the historical macro-story raises questions of referentiality and reliability (Paget 1998:62). This led me to consider the impact on the viewer. Whilst it may seem absurd, it seems to me that there is a danger of the viewer confusing the chronology of events by presenting the narrator within an historical context and then again within contemporary settings. Derek Paget references Bourdieu's assertion that, in Bourdieu's view, a popular audience is always likely to prefer the uncomplicated and direct (Paget 1998:83). Therefore in subsequent drafts I have relied on the voice-over only. The use of voice-over is well established in documentary and thus a few remarks are often enough to establish the facts and/or draw the viewer's attention to a particular feature of the location in question (Kilborn 2003:104). In this sense the voice-over is a long established narrational device for providing contextual information and guidance as to where events are taking place (Kilborn 2003:183).

Does this approach work? Undoubtedly the answer is yes. There is an audience expectation that a narration will guide them through the story and aid the re-construction of the events. Seymour Chatman references David Bordwell's assertion that narration is a process, which is not, in its basic aims, specific to any medium (Wartenburg and Curran 2005:195). Therefore it does seem reasonable to suggest that the primary role of narration is one where the audience arrives with an expectation of the nature of the narration, which they have acquired as a result of previous experience. This shows that in this project, a well-scripted narration was vital to ensure that the story was carried along in a manner that was clearly understandable to the audience. Dornan-quotes Funkhouser and Maccoby's 1973 study that generated 'rules' for effective composition of writing to communicate science. The rules are:

- urge scientists to be explicit
- use analogy
- use short sentences with short words
- mention practical applications.

Dornan in Scanlon, Whitelegg and Yates (1999:187)

This is as true for mathematics as it is for science and is the reason why I have written the actual mathematics in programme one in, what I would regard as, an accessible way.

<u>The role of the author as the creator of narrative</u>

This is difficult to analyse since by being both author and critic the analysis becomes, effectively, self-referential. It is a little like confession in a public place, whilst it may be ultimately good for the soul, the actual act itself can be self-destructive. However, as a writer I wanted to achieve one particular aim and that was to bridge the gap between intellectualism and the ordinary reader. C. John Holcombe (2007) shows how Barthes claimed to have unmasked the pretensions of romanticism and realism. Here Barthes suggests that there are two effective roles of the author, what he calls the écrivant and écrivain. The écrivant uses language to express what is already there whilst the ëcrivain is absorbed into the activity of writing, labouring and moving towards new elaborations and meanings. Therefore I feel justified in stating that my writing is écrivain, since as Holcombe states, this type of writing bridges ‘the gulf between the intellectuals and the proletariat’. This was very much my intention, to make accessible and visible the abstract language of the universe.

Bibliography

Anderson C. 2006 *The Long Tail: how endless choice is creating unlimited demand,* Random House, London.

Baker M. 2006 *Documentary in the Digital Age,* Focal Press, Oxford.

Barnouw E. 1993 *Documentary: a history of the non-fiction film,* OUP, Oxford.

Bragg M. 1998 *On Giants Shoulder's: Great scientists and their discoveries from Archimedes to DNA,* Hodder and Stoughton, London.

Braine J. 1974 *Writing a Novel,* Methuen, London.

Brande D. 1983 *Becoming a Writer*, Papermac, London.

Bronowski J. 1973 *The Ascent of Man*, BBC, London.

Bourdieu P. 1998 *On Television,* The New Press, New York.

Bruzzi S. 2000 *New Documentary: A Critical Introduction,* Routledge, London.

Burke J. 1978 *Connections,* Macmillan, London.

Burke J. 1985 *The Day the Universe Changed,* BBC, London.

Burke J. 1996 *The Pin Ball Effect,* Little Brown, New York.

Castro D. 2000 ' Erlebnis of Story' in *Phenomenology of Life and the Human Creative Condition* Anna-Teresa Tymieniecka, (ed.), Walters Kluwer, Netherlands.

Chatman S. 2005 The Cinematic Narrator in T.E. Wartenburg, A.Curran, *The Philosophy of Film,* Blackwell Publishing, Oxford

Clarke A.C. 2006 Preface: 'Welcome to the Joy of Maths', in *Understanding Maths: Basic Mathematics Explained* Graham Lawler (Studymates III ed. Abergele)

Corner J. 1996 *The Art of Record,* Manchester University Press, Manchester.

Corner J. 1999 'Documentary, The Transformation of a Social Aesthetic' in *Television and Common Knowledge,* Jostein Gripsrud (ed.), Routledge, London.

Dornan C. 1999 Some Problems in Conceptualising the issue of 'Science in the media' in E. Scanlon, E .Whitelegg. and S.Yates. *Communicating Science: Contexts and* Channels Reader 2 *Routledge, London*

Ellis J. 1999 'Television as working through' in *Television and Common Knowledge,* Jostein Gripsrud (ed.), Routledge, London.

Fauvel J. & J. Gray. 1987 *The History of Mathematics,* Macmillan, London.

Forster E.M. 1974 *Aspects of the Novel,* Penguin, London.

Godin S. 2000 *Unleashing the Idea Virus,* Simon and Schuster, London.

Grisprud J. (ed.) 1999 *Television and Common Knowledge,* Routledge, London.

Hampe B.1997 *Making documentary films and reality videos: a practical guide to filming and editing documentaries of real events,* Owl Books, New York.

Hogben L. 1938 *Mathematics for the Million,* Unwin, London.

Hogben L.1938 *Science for the Citizen,* Unwin, London.

Hutton W. 1996 *The State We're In,* Vintage, London.

Joseph G.G. 1991 *The Crest of the Peacock: Non-European Roots to Mathematics*: IB Taurus, London.

Johnson R. 2004 *Hitler and Nazi Germany: The Seduction of a Nation,* Studymates, Taunton.

Johnstone R.J., D .Gregory., G. Pratt., M.Watts. (ed.),. 2000 'Actant Networks' in *The Dictionary of Human Geography,* Blackwell, Oxford.

Jute A.1986 *Writing a Thriller,* A & C Black, London.

Jute A. 1992 *Keep on Writing: from creative writer to professional writer,* David St John Thomas, Nairn.

Jute A. 1990 *Start Writing Today,* David and Charles, Newton Abbott.

Kelsey G. 1990 *Writing for Television,* A & C Black, London.

Kilborn R., J .Izod 1997 *An Introduction to Television Documentary: Confronting Reality,* Manchester University Press, Manchester

Kilborn R. 2003 *Staging the Real,* Manchester University Press, Manchester

Koontz D.1981 *How to Write Best Selling Fiction,* Popular Press, London.

Kuhn T.S. 1996 *The Structure of Scientific Revolutions,* (3rd ed) University of Chicago Press, London.

Lawler G. 2006 *Understanding Maths,* (3rd ed), Studymates, Abergele.

Legat M. 1992 *Plotting the Novel* Robert Hales, London.

McCleish J. 1991 *Number: from cave people to computers, a revolutionary view of* *ourselves,* Bloomsbury, London.

Morley D. 1999 'Finding Out About the World from Television News', in *Television and Common Knowledge*, Jostein Gripsrud (ed.), Routledge, London.

Murdock G. 1999 'Rights and Representations', in *Television and Common Knowledge,* Jostein Gripsrud (ed.), Routledge, London.

Nichols B. 2001 *Introduction to Documentary,* Indiana University Press, Indiana.

Nichols B. 2005 'The Voice of Documentary', in *New Challenges for Documentary* A. Rosenthal and J.Corner (ed.), Manchester University Press, Manchester.

Okigbo C. 1995 ' Africa: Television and National Independence', in Smith A. (ed.), in *Television: An International History*, OUP, Oxford.

Oliver M. 2005 *Writing Historical Fiction,* Studymates, Abergele.

Orwell G. 1984 *The Penguin Essays of George Orwell,* Penguin, London.

Paget D. 1998 *No Other Way to Tell It,* Manchester University Press, Manchester

Pledge H.T. 1966 Science *since 1500,* HMSO, London.

Reich R. 1991 *The Work of Nations: a blueprint for the future,* Simon and Schuster, London.

Rodham-Clinton H. 2004 *Living History*, Headline, London.

Rosenthal A.2002 *Writing, Directing and producing documentary films and videos,* Southern Illinois University Press, Southern Illinois.

Rennie L. and. T .McClafferty 1999 Science Centres and Science Learning in E. Scanlon E.Whitelegg and S.Yates *Communicating Science: Contexts and Channels Reader 2* Routledge, London

Shapin S. 1996 *The Scientific Revolution,* University of Chicago Press, London.

Singh S. 1997 *Fermat's Last Theorem,* Fourth Estate, London.

Singh S. 1999 *The Code Book,* Reed, London.

Smith A. (ed.) 1995 *Television: An International History*, Oxford University Press, Oxford.

Snow C.P. 1998 *Two Cultures*, Cambridge University Press, Cambridge.

Sobel D. 1999 *Galileo's Daughter,* Fourth Estate, London.

Sobel D. 1996 *Longitude,* Penguin, London.

Taylor B. H. 2000 *Writing from Experience,* Robert Hale, London.

Thompson F.1998 'Fordism and Post Fordism', in the *Encyclopedia of Political Economy,* Routledge, London.

Ward P. 2005 *Documentary: the margins of reality,* Wallflower Press, London.

Wetton S. 2005 *Writing TV Scripts,* Studymates, Abergele.

Wheen F.1985 *Television,* Century, London.

Winston B. 1995 *Claiming the Real,* BFI, London.

Winston B. 2000 *Lies, Damned Lies and Documentaries,* BFI, London.

Woolley B. 1999 *The Bride of Science: Romance, Reason and Byron's Daughter,* Macmillan, London.

Vaughan D. 1999 *For Documentary*, University of California, London.

Zalavasky C. 1990 *Africa Counts* Lawrence Hill, Chicago.

Ph.D. Thesis

Greenslade D.2001 *Cambrian Country,* Ph.D. Thesis, Cardiff.

Television Programmes

Ackroyd P. 2004 *Peter Ackroyd's London,* BBC, London.

Bashir M. 2003 *Living with Michael Jackson,* Granada TV, London.

Beckham M. 1990 *Who Bombed Birmingham?* Granada TV, London.

Burley L. 2004 *He's Starsky, I'm Hutch*, Monkey Productions, London.

Radio Programmes

B.B.C. Radio 4 FM Oct 28th 2005 *The Message*, BBC, London.

Websites

ABC *TRANSCRIPT Abraham Zapruder Interview*: November 22, 1963. Jay Watson talking to Abraham Zapruder. The Sixth Floor Museum 2002-2006, http://www.jfk.org/Research/Zapruder/Transcript.htm, accessed on 27/05/06.

About Enigma and Its Decryption, http://homepages.tesco.net/~andycarlson/enigma/about_enigma.html, accessed on 18/06/06.

Actor Soul angry over documentary, http://news.bbc.co.uk/1/hi/entertainment/tv_and_radio/3515742.stm 16/03/04, accessed 16/03/04

Addie B. and A Nelson. July 2004 A Documentary Identities ATOM National Conference, www.studentnet.edu.au/aispd/literacy, accessed on 23/06/06.

Apollo 13 http://www.math.iupui.edu/m261vis/A-13.html, accessed on 20/06/07.

Apollo 13: A Successful Failure, http://liftoff.msfc.nasa.gov/Academy/History/APOLLO-13/mission-report.html, *Excerpted from W. David Compton, Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions (Washington, D.C.: NASA SP-4214, 1989), pp. 386-93,* accessed on 20/06/07.

A short history of Probability and Statistics, http://www.leidenuniv.nl/fsw/verduin/stathist/stathist.htm, accessed 25/06/07.

A short history of Probability, http://www-static.cc.gatech.edu/classes/cs6751_97_winter/Topics/stat-meas/probHist.html, accessed 25/06/07.

Barsamian D. 2004 *Liberating the Mind from Orthodoxies: An Interview with Noam Chomsky,* www.zmag.org/Zmag/articles/may/01barsamian.htm, accessed 25/06/07.

Becker J. 1998 *Verisimilitude,* http://www.beckerfilms.com/verisimilitude.htm, accessed 31/06/06.

Beller J.L. 1999 *Dziga Vertov and the Film of Money Boundary 2,* http://muse.jhu.edu/demo/boundary/v026/26.3beller.html, accessed 28/05/06.

Bletchely Park National Codes Centre, http://www.bletchleypark.org.uk/, accessed 18/06/06.

Brabazon T. 2005 *What have you ever done on the telly? The Office, (post) reality television and (post)work Cultural Studies* Sage Publications London, http://ics.sagepub.com/cgi/reprint/8/1/101, accessed 28/05/06.

Burke J. *Making the Connections between the technology of today and the learning of Tomorrow,* www.educase.edu, Oct 13-16 1998, accessed 04/06/06.

Burke J. 1999 *The Knowledge Web: Voices from the Smithsonian Associates,* http://smithsonianassociates.org/programs/burke/burke.asp, accessed 04/06/06.

Captured U-boats, http://uboat.net/fates/captured.htm, accessed19/06/06.

Catalogue Niccolò Tartaglia, http://www.mhs.ox.ac.uk/geometry/cat1.htm, accessed on 20/06/07.

Douglas D. *Behind the Camera* Adapted from comments by on the NFB Web site XS Stress: Teens Take Control, www.onf.ca, accessed 07/05/06.

Enigma: an enigma simulator site, www.xat.nl/enigma/, accessed 18/06/06.

Felberbaum A *Somewhere between here and there narrativas contadas narrativas vividas* , www.narrativas.aliciafelber.com, accessed 22/06/6

Figures from the History of Probability and Statistics, http://www.economics.soton.ac.uk/staff/aldrich/Figures.htm, accessed 25/06/07.

Ford H. *Brainy Quote,* http://www.brainyquote.com/quotes/quotes/h/henryford109833.html, accessed 15/03/07.

Ford H. 2007 *You can paint it any color, so long as it's black,* http://www.hfmgv.org, accessed 17/11/07

Freund C. P. 2006 *Missing Links: The vast international conspiracy behind the Zapruder film,* http://fromthedarkstream.bloghi.com/2006/02/28/the-zapruder-film- conspiracy.html , accessed 22/05/06.

Garfield E. 1980 *Science on Television,* www.garfield.library.upenn.edu, accessed on 04/06/06.

Girls rock, www.girlsrockmovie.com, accessed 23/05/07

Happy Birthday Ada Lovelace, www.adahome.com, accessed 16/09/07.

Herbert Windt, http://www.imdb.com/name/nm0934819/, accessed 05/05/08

History of Statistics and Probability, http://www.mrs.umn.edu/~sungurea/introstat/history/indexhistory.shtml, accessed 25/06/07.

Hitler's Enigma, http://www.lawbuzz.com/tyranny/u571/u571_ch4.htm, accessed, 19/06/06.

Holcombe C.J. 2007 Roland Barthes http://www.textetc.com/theory/barthes.html accessed 05/05/08.

Institute and Museum of the history of science, http://www.imss.firenze.it/, accessed, 20/06/07.

James C. 2007 *Ruby Wax Talking in the Library,* www.clivejames.com, accessed, 20/06/07.

James C. 2007 *Jonathan Miller Talking in the Library,* www.clivejames.com, accessed, 20/06/07.

James M. 2006 *Welcome to Potters Bar- the victims stories* (Dir.Sayers J. 2006 Exec Prod Roger Graef Films of Record BBC1 December), www.filmsofrecord.com, accessed 23/06/07.

Kelliher A., Mazalek A, Davenport G 2003 *Documenting Digital dialogues: engaging audience in the construction of a collective documentary across Time and Space,* http://alumni.media.mit.edu/~mazalek/publications/DigitalDialogues-TIDSE03.pdf , accessed, 22/06/06.

Kershaw A. 24/05/07 *The Woman who gave the Nazis their glamour,* www.telegraph.co.uk, accessed 24/05/07

Lakoff G. 1987 *Women, fire and dangerous things, what categories reveal about the mind* University of Chicago Press, http://vonneumann.cog.jhu.edu/faculty/smolensky/050.326-626/Foundations%20Readings%20PDFs/Lakoff-1987-WomenFire-Pref&Ch2-INCOMPLETE.pdf, accessed, 28/05/06.

Lancaster P. *Mathematics and society,* http://www.thecanadianencyclopedia.com, accessed 28/08/06.

Lawrence D., Thomas J.C. 1999 *Social dynamics of storytelling: Implications for story-base design* - group of 3 - Proceedings AAAI Fall Symposium on Narrative, www.citeseer.ist.psu.edu, accessed 28/08/06.

Maclennan B. PhD 2005 *Goethe, Faust, and Science,* www.cs.utk.edu/~mclennan/Classes/UH348/index.html, accessed 18/02/07.

Martin L. T. March 1, 2004 *Reconstructing the JFK assassination,* www.broadcastengineering.com , accessed 21/02/07.

Materials for the History of Statistics, http://www.york.ac.uk/depts/maths/histstat, accessed 25/06/07.

Nova online: How the Enigma Works, http://www.pbs.org/wgbh/nova/decoding/enigma.html, accessed on 18/06/06.

Ohayon A. *The development of the documentary at the NFB during the Second World War and in the years that followed.* in Behind the Camera NFB Canada, http://www.onf.ca/enclasse/doclens, accessed 07/05/06.

Peenemunde – 1943, http://www.globalsecurity.org/wmd/ops/peenemunde.htm , accessed 20/06/07.

Pfanner E. *When You Tube is a Threat,* International Herald Tribune, April 22 2007, www.iht.com, accessed 25/06/07.

Rao A. 2001 *Interconnections of Science and the Arts,* http://www.physics.vanderbilt.edu/courses/sth209/gscience.html, accessed 18/02/07.

Riefhenstahl L. http://www.riefenstahl.org/director/1935/, accessed 23/03/07.

Rockets in World War II, http://www.allstar.fiu.edu/aero/rock3.htm, accessed on 20/06/07.

Smith D.M. 2003 *The Gartner Fellows Interview,* http://www.gartner.com/research/fellows/asset_60126_1176.jsp, 04/06/06.

Snowden B. *The Curious History of the Gregorian Calendar,* http://www.infoplease.com/spot/gregorian1.html, accessed 12/04/99

The Henry Ford, http://www.hfmgv.org, accessed on 24/11/07

Thompson F. 2005 *Fordism, post-fordism and the flexible system of production* Atkinson Graduate School of Management, Willamette University, Salem, Oregon. 97301, http://www.willamette.edu/~fthompso/MgmtCon/Fordism_&_Postfordism.html, accessed 12/02/07.

The Alan Turing Internet Scrapbook *Critical Cryptanalysis: The Enigma War, 1939-1942,* http://www.turing.org.uk/turing/scrapbook/ww2.html, accessed on 18/06/06.

The Enigma cipher machine, http://www.codesandciphers.org.uk/enigma/, accessed on 18/06/06.

The MacTutor History of Mathematics archive, http://www-history.mcs.st-and.ac.uk/ , accessed on 20/06/07.

The Morecambe and Wise Show 1977, http://www.televisionheaven.co.uk/morecambeandwise.htm, accessed 15/06/06.

The Secret of the U-110, http://www.ihffilm.com/r543.html, accessed on 19/06/06.

Webber T. *BBC strikes Google-YouTube deal,* www.bbc.co.uk/news, Friday, 2 March 2007, accessed 02/03/07.

Welcome To Potters Bar A Rail Cops Special - The Victims Stories, http://www.filmsofrecord.com/productions/productions_potters_bar.htm, accessed 17/11/07

What is good writing? http://writingcenter.emory.edu/goodwrite.html, accessed on 27/01/06.

What really happened to Apollo 13? , http://www.ghg.net/woodfill/TRACT13.html, accessed on 20/06/07.

Yates B.L. *Media Literacy and the Policy making process: a framework for understanding influences on potential educational output*, http://www.utpjournals.com, accessed 06/03/07.

Ziolkowski T. 1981 *Science, Frankenstein, and Myth, Sewanee Review*, 89:1 34-

56, http://www.english.upenn.edu/Projects/knarf/Articles/ziolko.html, accessed 18/02/07