Against Chronological and Impersonal Accounts of the History of Science. Towards non-linear didactics

Almagest

Gustaaf C. Cornelis

Vrije Universiteit Brussel

E-mail: gccornel@vub.ac.be

Abstract

This paper criticizes traditional chronological teaching, instigated by recent studies by Kinchin that show how linear computer presentations barely contribute to the student's understanding of the subject matter. I introduce non-linearity in teaching history, in particular in teaching history of science, as an alternative to standard didactics. Timelines are fundamental to linear teaching, but they are also valuable as a supplement to non-linear accounts. Hence, it is anticipated that a hybrid account (combining a non-linear approach with an evidently linear timeline "on the side") serves an adequate understanding of the history of science better. An elaborated non-linear account of early radio astronomy is chosen as illustration. My aim is to contribute to a more efficient, adequate and above all sincere didactics of the history of science.

Traditional teaching

As historiographers, we all look at the past through our own coloured glasses. Nevertheless, classroom accounts of history are taken for granted by students and viewed upon as indisputable. As series of supposed facts, chronicles actually enumerate black boxes: stripped events, presented chronologically, date between brackets. Each account is evidently an interpretation, but details on whom, why and how are missing: the narratives are black boxes too. The idiosyncrasy of the historians remains obscured. We see what we want to see, we teach how we see it, but are our students aware of all this? Shouldn't we tell them about the colour of our glasses?

Openness is the starting point of adequate teaching. Honesty is the *conditio sine qua non* to a better understanding, but it is not sufficient. Historical facts and accounts are constructions. Specialists interpret events; these interpretations are validated and turned into facts. Scholars list facts and create accounts. Lecturers give talks supported by computer presentations. Students study bulleted lists – considered as excellent, at least convenient summaries to learn by heart. Some students will even make up stories only to serve recollection. Students take exams and rattle off the subject material, and confabulate from time to time. Do they really *grasp* history? Examiners are surprised to hear things they never talked about during class. Even if the instructors are truthful about history and historiography, still things go wrong.

Recent research by Ian Kinchin shows that linearly structured computer presentations do not serve an understanding of the subject matter. Historical accounts are evidently linear, thus maybe here the shortcoming can be pinpointed and a non-linear approach might help us out.

At the content level, it is necessary to teach unreservedly, but also at the methodological level things have to change. Can traditional teaching be altered in view of more efficient didactics? This paper lists the disadvantages of linearity and proposes non-linear didactics as remedy. A historical case study that deals with early radio astronomy is offered as an illustration. A research design is also delineated in this article.

The disadvantages of linearity

Due to the perceived structure of time, history is naturally ordered in a linear fashion. Bulleted lists are helpful in teaching and learning. Nevertheless, we need to do better. Ian Kinchin (Kinchin 2009) argues that the linear teaching instructors are "forced" to by presentation software as *PowerPoint*, *Flash*, *Impress* and *Keynote*, hardly contributes to students' understanding (Kinchin 2008). These computer programs provide students with shallow, inert, and "decontextualised" chunks of information. Teachers use the summaries as reminders when they reconstruct parts of history. Even so, the entries generally lead to anecdotal and/or brief comments, so-called *black boxes* (Latour 1987).

A lot of current courses miss what is vital to insight: usual presentations do not focus on conceptual bridges and relations between events. This information is trivially available in the author's or lecturer's mind, but it is concealed in the listed black boxes with only the historical facts written on the outside of the virtual box followed by a date between brackets. Although the box's content gives the insights necessary to grasp history as constructed by historians, people are not generally interested in what the box carries (Latour 1987). Which is regrettable, because in the black box lies the key to a profound comprehension of the metier: science without compromise (Cornelis 1998).

It is not only computer-assisted lectures that suffer this deficiency; most handbooks are linear as well, although they are more explicit and detailed in content. The solutions I propose here pertain to oral presentations and written accounts alike (Cornelis 2009). Nonetheless, coupled with linear presentations, the problem reoccurs for non-linear lectures, because lists are always welcomed as capitulations. They should not, because they lack too much information. Furthermore, most accounts, whether written or oral, hide what is present in the teacher's mind, exactly because they are linear and, hence, restrictive. The view of the teacher can be as adequately transferred to the student as the presentation allows. The presentation works indeed as a bottleneck (Fig. 1).

Figure 1: *The features of the presentation reduce the adequacy of knowledge transfer*

Nil novum sub sole: all means of communication influence the content of a message, while noise (not discussed here) will distort the message. New is the fact that the structure of a message, i.e. linearity, effected by the medium, i.e. computer presentations, or the subject, i.e. history, highly bears on the adequacy of knowledge transfer, i.e. the understanding of history. In other words, an alternative way of teaching history might provide teachers with an opportunity to present history overtly, in more adequate manner and in a more efficient way.

Remediation

To counteract the unfavourable effects of linearity, the solution lies in a non-linear approach to teaching, a fortiori to the didactics of history of science. John Dewey, the archetype of educational reformist, already wrote at the beginning of the 20th century: "Just because the order is logical, it represents the survey of subject matter made by one who already understands it, not the path of progress followed by a mind that is learning" (Dewey 1910, 204). To learn about history in order to understand history, the apparent structure as provided in class needs to be replaced by or at least supplemented with the previously hidden interpretation of the scholar.

How can it be done? Instead of an annotated linear-chronological presentation that focuses on black boxes, the teacher gives the events in an order determined *by his own associations*. This is the essence of the new model. Obviously, accounts will differ to a great extent, although the same series of events are covered. This non-linear approach has several advantages. The focus now lies on relations between events, not necessarily causal, but thematic or associative, and unambiguously related to the scholar that presents his view on a part of history. It is of utmost importance that it becomes clear to the audience that it is a personal account, scientifically developed, with the background theory sufficiently provided. "Scientifically developed" means to me in this context that the view, personal and therefore evidently subjective, is an opinion based on scientifically gathered material (articles published in peer-reviewed journals, experiments, qualitative or quantitative research, etc.) The new approach comes to focus on probable and plausible connections between events rather than events itemized chronologically and no more than that.

Presentations of a non-linear approach appear to be linear too. The non-linear account is then presented in a linear way, because it merely concerns a new ordering of elements, given an articulated background theory uniquely linked to a particular scholar. It is evident that one should attempt to present a non-linear story in a way that serves, even enhances non-linearity, e.g. by using "networks" or "webs" but avoiding animations, because an order of appearance implies a sequence.

Kinchin shows that substituting linearly structured slides by non-linear slides, providing the audience with "networks", "webs", "diagrams", etc. in stead, is possible and has the desired effect (Fig. 2). While the linear slide "utilises one of the style templates available with PowerPoint, resulting in a list of six bullet points" (Kinchin 2007, 195), the content on the non-linear slide, also meant as an introductory PowerPoint slide on "Effective partial denture design" is arranged "as a concept map that emphasises the links between the main elements" (Kinchin 2007, 196).

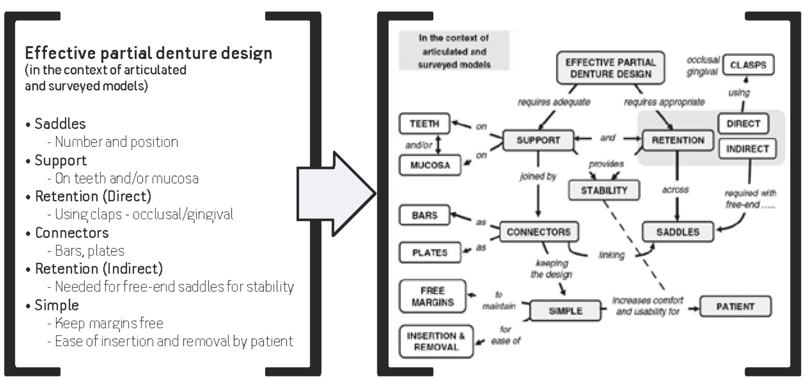

Figure 2: *A linearly structured slide can be replaced by a non-linear design that better serves non-linear approaches*
(Based on Kinchin 2007, Fig. 1 and 2)

Kinchin concludes that "students in this study were quite clear in their opinion that a bullet-pointed list is more useful than concept mapping if the aim is to memorise facts (i.e. a surface approach to learning). But they were just as clear that concept mapping is a more useful strategy if the aim is to make links between ideas and therefore gain a better understanding of the subject (i.e. a deep approach to learning)" (Kinchin 2007, 198). I want to prove that more generally a non-linear approach of the history of science equally improves "a better understanding of the subject". To do so, I propose a blind experimental setting in which some students will effectively experience non-linear teaching.[1]

Hybrid didactics

It would be absurd to completely disregard the chronology of events, whether there is a causal relation involved or not. Parallel timelines are nonetheless interesting, sometimes indeed revealing, because they hint at possible causal relations and suggest a holistic approach. Hence, they fit the non-linear view on the didactics of history in a seamless manner. A plain one –or two– dimensional timeline –linear *per se*– should be furnished, *after* the non-linear account.[2] Again, the timeline only refers to the chronology – otherwise it can be seen as a sum-up. This hybrid approach (a non-linear account complemented with a timeline) cannot be unconditionally applied. A rash introduction of a timeline –with details– can lead to the opposite effect.

For an ideally complete understanding it might be expected that thoughts, ideas and theories from philosophy of science should be included. Or as Imre Lakatos has put it: "Philosophy of science without history is empty, history of science without philosophy of science is blind" (Hacking 1981, 107). And yet, including explicitly and comprehensively philosophy of science might actually thwart an easy understanding of history. The game, some might say, is not worth the candle. However, any scholar of the history of science does hold a philosophy of science.

Adequacy suffices here, but this cannot be reached easily through pure non-linearity alone. Simply providing a chronological overview, a timeline for example, would facilitate some kinds of insight. However, this linear tool is secondary to the non-linear main story. When a plain chronology is provided afterwards, the non-linear narration itself does not have to bother with dates.

The combination of a primary non-linear discourse and a secondary linear timeline promises to be advantageous. Kinchin (2010) argues for dual processing of information, combining "chains" and "nets", i.e. linear and non-linear accounts. I suggest a hybrid approach, combining the better of two didactic methods.

1 See "Testing non-linear teaching".
2 See "In practice".

A case study

"Early Radio Astronomy" (ERA) concerns the beginning of stargazing in low frequencies. Southword (1956) wrote the very first, to my knowledge, article about ERA, whereas Sullivan ([1984] 2004) published a complete overview.

I will now proceed with the details of ERA in a linear fashion. Usually the story (as in both examples) starts with the 1930 research of Karl Jansky on static noise. Marvin Skellett told Jansky it could be of cosmic origin, but Jansky later inferred the phenomenon was related to the galaxy. Grote Reber introduced the parabolic telescope[3] into radio astronomy as well as the isoline representation.[4] About ten years later, Martin Ryle identified many radio-sources. He applied the principle that the weakness of a signal was a measure for the distance. This introducing chat on ERA could be supported by a standard linear slide (Fig. 3).

- **Jansky (1930)**
  - Static noise reserch
  - Skelett: "it could be cosmic"
  - Galactic origin
- **Grote Reber (1938)**
  - Parabolic Radio Telescope
  - ISO-line representation
- **Martin Ryle (after WW2)**
  - Identification of many radio-sources
  - Principle: weaker → further

Figure 3: *A standard structured slide to back up a talk on early radio astronomy*

The above paragraph exactly states what is there on the slide, and vice versa. During the talk a lecturer will most likely add that the static noise was picked up by telephone, and that therefore Bell Telephone Laboratories became interested in the phenomenon too. Jansky, working for Bell, did put up a telescope at the Holmdel site (of Bell). His friend Marvin Skellett, who happened to be an astronomer, inspired and encouraged him to do so. During the 1930s, militarization steered the applied sciences and as a result radar

3 A parabolic telescope looks like a dish antenna.

4 An isoline representation is a way of depicting intensities by colours, ranging from blue (low) to red (high). Isolines connect the points with the same intensity, mark the regions of comparable intensity and, hence, display the gradient of the magnitude over an area.

technology was further developed. Reber wanted to work for Bell, but did not get a job; so he continued Jansky's research in his free time. He discovered the synchrotron radiation. The isoline representation was by that time utilized in many disciplines, all following meteorology. Martin Ryle was not the only one, of course. The principle Ryle used goes back to Edwin Hubble in 1925: "smaller and/or weaker means further" (Fig. 4).

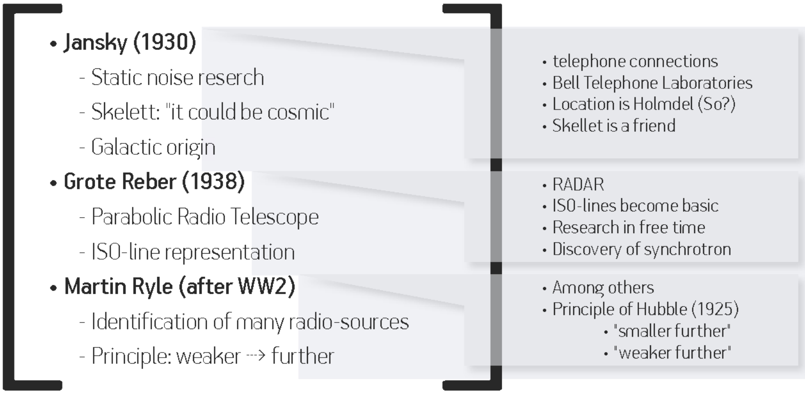

Figure 4: *During presentation, a lecturer could provide the students with additional information, directly linked to the topics already on the slide. What is written here in the call-outs is not on the screen, but told by the lecturer*

Computer presentations save up time. They are versatile, easy to adapt and reusable with little or no effort. During a lecture, no time is lost using black board or flipchart – although the combination of slides with a limited use of a board is recommended from a didactical point of view (as every change helps students focus). One could argue that there is time left then to go deeper into matters, due to the use of slides. However, from the point of view of the audience, all that is told "off screen" is less important. Evidently, it is easy to throw in another slide, to give more details. That, however, is not the issue here. The problem is that the linear presentation forces both the lecturer and student in a confining way of looking at the topic presented.

What would we really want to tell our students? If it regards ERA, maybe it would be interesting to question the way in which Jansky came to his findings. Was it a case of serendipity or not? There are many reputed instances of serendipity that can be proven otherwise; e.g., the discoveries of lysozyme, special relativity theory and cosmic background radiation (Cornelis 2000). Jansky's work will eventually lead to the discovery of cosmic background radiation (CBR), with Arno Penzias and Robert Wilson in 1964. The instruments they all worked with are astonishingly modest and look quite non-professional. The pivoting antenna ("Jansky's merry-go-round"), put up at the Holmdel site, was made out of a wooden skeleton and wires.[5] A horn antenna[6] was constructed at the same location in 1959: Penzias and Wilson would use it. Reber's adaptation of the parabolic "dish" antenna for radio astronomy is comparable to Galileo's change of use of the telescope for astronomical observations. As Galileo's application enlarged the scope of visual investigation, Reber's use of the dish telescope broadened the astronomical spectrum. His introduction of isolines in radio astronomy places him in a tradition started by Alexander von Humboldt in the 19th century: the latter developed the theory of isothermal lines in 1817 (Knobloch 2006, 38). Martin Ryle was Fred Hoyle's foe: during the 1940s, Hoyle developed an alternative to big bang cosmology, the theory Ryle adhered to, and which got confirmed by the discovery of CBR.

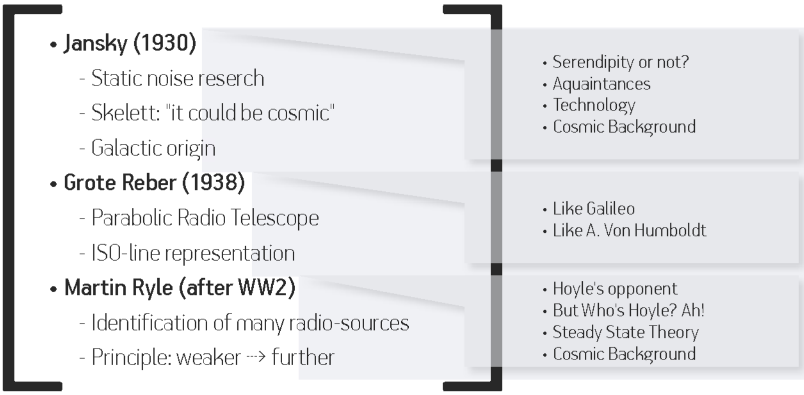

Figure 5: *What a lecturer on ERA really wants to tell. The call-outs represent the background knowledge of the scholar*

And yet, the search for CBR seems to be the background story to ERA. Of course, one can opt for a story on CBR, of which ERA is part. Then again, a linear account arises and most probably the slide as pictured in Fig. 3 (or slightly adjusted) will be presented. All flaws of linearity re-emerge.

ERA preoccupies as the subject matter of their research quite a few historians of science. Each scholar has his of her own views on the topic. My cognitive map of ERA looks as visualised in Fig. 6.

5 It is a straightforward antenna: metal wires stretched between poles.

6 Quite different from a dish antenna, the horn antenna converges the incoming radiation and reflects the beam horizontally in the direction of the receiver.

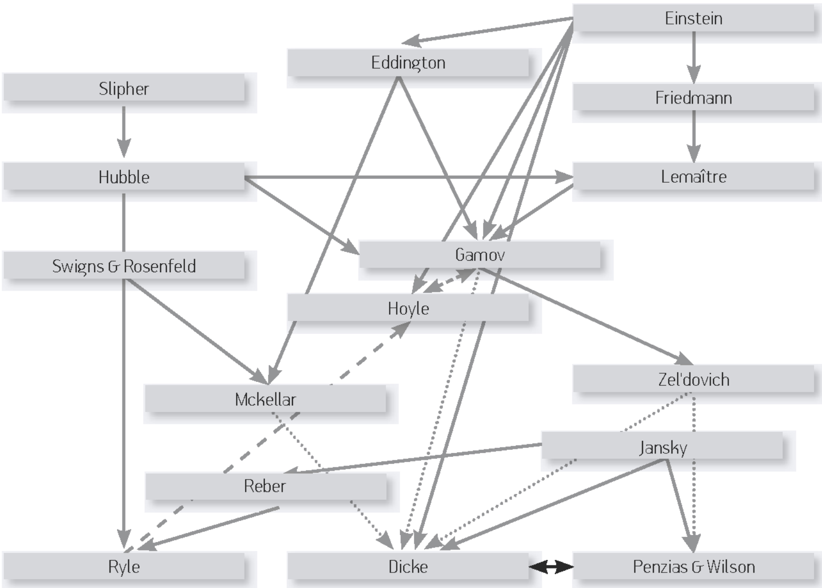

Figure 6: *Cognitive map of ERA, depicting direct influences. Striped lines: opponents. Dotted lines: implicit influence*

It is a cognitive map related to one person and one moment in time. The map can be used in preference to the linear slide presented in Fig. 2. It does ask a lot of the lecturer, because the story needs to be reconstructed "in situ". Students need to pay a lot of attention and take many notes – unless the textbook is following the same lines (which is typically not the case). The "net"-slide is evidently useless as a summary, but it does show better how history works. Without additional information and a path connecting the various entries, both of which will be supplied by the lecturer, the "net" is meaningless. The slide is reduced to what it should be: a support, not a summary (Fig. 7).

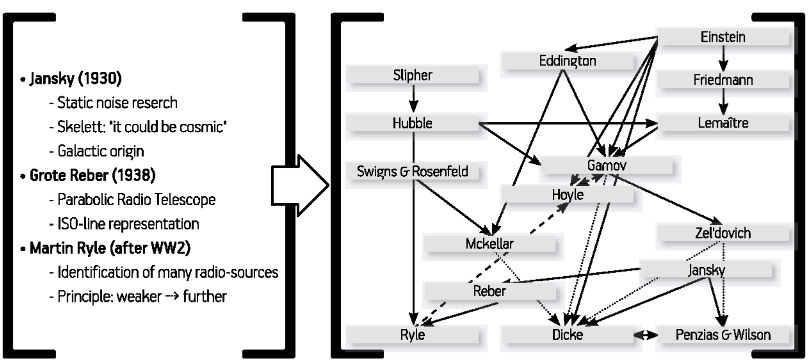

Figure 7: *Using a cognitive map as a non-linear slide. Compare to Figure 2*

Now it looks like it all started with Einstein's publication of 1917 (Einstein 1917). Pouring down the cognitive map into a structure results in yet another inevitable linear development (Fig. 8). Besides, the lecturer chooses a story line out of almost an infinite number of possibilities. Such a diagram is highly questionable: it suggests a chronological order that is incorrect.

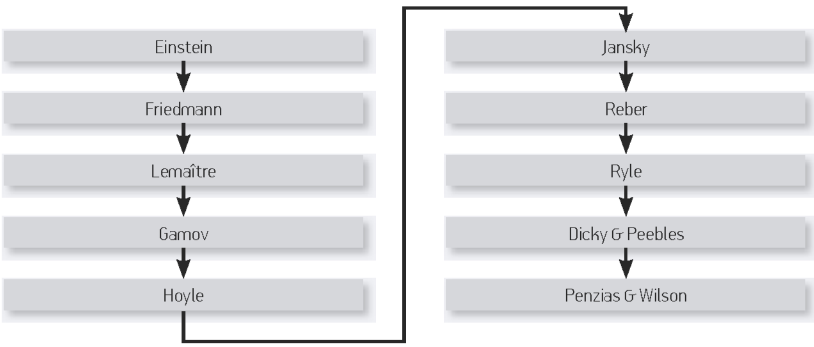

Figure 8: *Making a story out of a cognitive map*

Instead of a focus on the astronomers and cosmologists, it is of course thinkable to tackle the issue using a thematic approach. Doing so, one does depart from the core idea that ERA is a venture of a handful of scholars and, hence, the attention to the sociological aspects tends to fade away (Fig. 9).

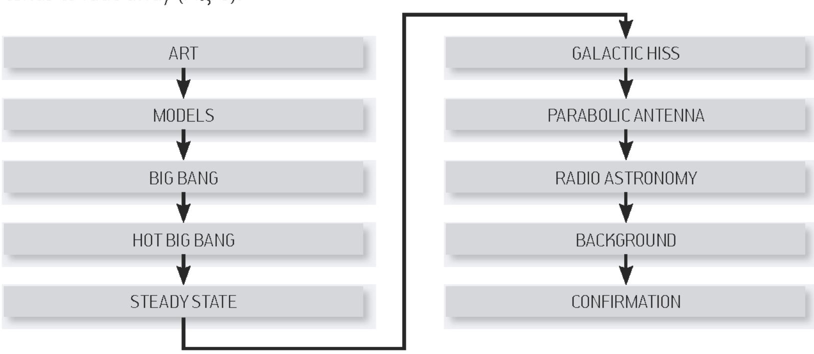

Figure 9: *Making a thematic story out of a cognitive map*

To avoid linearity as much as possible, I advance now a circular account to ERA.[7] The story[8] starts

7 I will not provide any references here, except for citations. Some details can be found in e.g. Southword (1956) or Sullivan ([1984] 2004), other in so many overviews of modern astronomy. Actually, they do not matter here, because the account given is mine, coloured by my "glasses".

8 This account serves as an illustration of a non-linear story. It is non-fiction, but concise, and should not be seen as a complete and adequate account of ERA. This is not the purpose of this paper. I present it here only to give the reader an idea of a non-linear discourse.

with Jansky and ends with Jansky. I have chosen to proceed conventionally from Jansky to Reber and then to Ryle. However, after the introduction to Jansky, citing his work for Bell and Skellett's solution to the problem, Reber comes to the foreground with his application of the parabolic telescope, which leads to further research by Ryle. Hoyle is announced as Ryle's opponent and Gamow's opponent as well. Gamow developed the astrophysics of the big bang theory, the details of which were unknown to Dicke who tried to measure the temperature of the universe as a remnant of a hot beginning. Even before Dicke's intentions, Zel'dovich drew attention to the Holmdel horn telescope as a suitable instrument to do so. In 1964 Penzias and Wilson had to solve a similar problem as Jansky dealt with thirty-four years earlier. Penzias and Wilson called Dicke on the phone and he explained their observations immediately. The situation is comparable to the exchanges between Jansky and his friend Skellett. Skellett was an astronomer, just like Dicke, while Jansky, Penzias and Wilson were radio-engineers. These are no cases of serendipity, however. McKellar discovered the presence of hydrocarbon in the interstellar medium: the spectral line only shows up with a temperature around -270° C. The ambient temperature therefore is 2,7 K, which is the same as the temperature inferred by Penzias and Wilson, and identified by Dicke. McKellar's measurement surfaces again in 1966. Hydrocarbon was first detected through spectroscopy in the atmosphere of young stars by the Belgian astronomers Swings and Rosenfelds. Lemaître, a fellow Belgian cosmologist but also a priest, developed the idea of a hot and dense start for the universe: in the beginning, the universe was as big as the solar system – quite a revolutionary view for a priest. Hubble, a die-hard empiricist of an astronomer, was –as was customary– not into speculation. However, he induced the distance-redshift relation, with bears his name. Although Hubble himself did not conclude the expansion of the universe, his observations lead to a further development of what would become standard theory, as soon his findings were combined with Lemaître's model. Hubble elaborated on Slipher's work that showed that the so-called nebulae (later identified as galaxies) moved away form the earth (with the system of Andromeda as an exception). Slipher was a practitioner, like Hubble, and was rather looked down upon by theoreticians like Friedmann. Friedmann reviewed Einstein's field equation, extended with lambda, the cosmological constant. Einstein introduced it to make his theory fit his rather static view of the universe: he did not know Slipher's contemporary findings, or else he neglected them. Eddington was Einstein's champion and would surely have questioned this accusation of narrow-mindedness. Einstein was chivalrous and later on he called the introduction of lambda his greatest blunder. This genuflexion was a blunder itself since lambda is manifestly present in current cosmology.[9] Eddington was so convinced of Einstein's relativity theory, that he "overlooked" falsifying evidence. Due to the limitations of the instruments at his disposal at that moment in time, the observations were actually more in favour of Newtonian theory. Eddington wanted to know the overall temperature of the universe and deduced a temperature of 3,18 K caused by the light coming form the stars. However, cosmic radiation, contrary to starlight, is evenly spread "more or less evenly over all space". Eddington argued: "In a general survey of radiation in the universe, only the cosmic radiation needs to be considered" (Eddington 1933 (1987), 81). Jansky found out that the

9 For example, Basilakos et al. 2009 and Tiwari et al. 2010.

distribution of radiation in the universe is far from being homogeneous (Fig. 10).

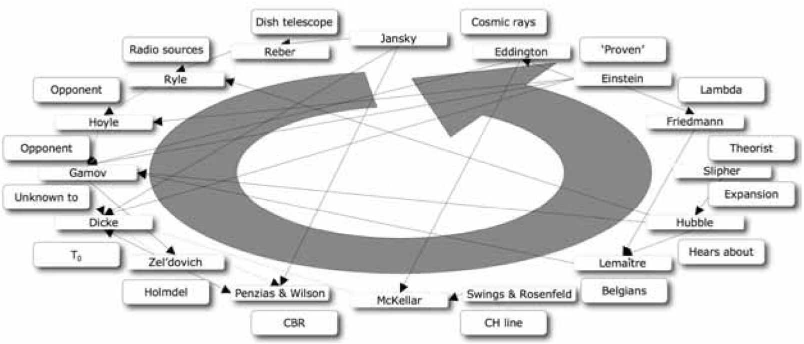

Figure 10: *A non-linear account of ERA, person-topic related*

The sequence of scientists and discoveries is only determined through associative thought by the lecturer and is therefore unique and contingent. Cross-linking is still possible, as is shown above: it only makes the story more intriguing. The map of Fig. 10 can be put on a slide as it is.

I conclude that a non-linear account: (1) delivers a story that makes sense; (2) is clear on the fact that it concerns a personal account by the lecturer; (3) highlights sociological, psychological and technological aspects; and (4) stresses that a development is more than a chronology. Above all, (5) this kind of account gives content to the black boxes. Regarding ERA, to this can be added that the non-linear account also (6) puts Jansky in the spotlight, where he should be, and (7) emphasizes that ERA cannot be thought of as an isolated development in astronomy. Of course, one can mention all this within a linear presentation, but it would be "just a remark" that will probably fail to make it into the long-term memory of the student.

In practice

It is actually easy to develop a non-linear scheme as in Fig. 10 to prepare a lesson. One can always decide to work "in situ", but some preparation can help to bring the lecture elegantly to a close. Any software that works with textboxes and connectors (e.g. to make flowcharts like SmartDraw or to design presentations like Powerpoint) will do: make a mind map, link the boxes, choose a starting point and put the boxes in a circle. There is nothing more to it.

In addition a chronology can and should be given as argued before. This can be a simple list of names and dates. However, a two-dimensional timeline is a better alternative (Fig. 11). This one shows names and dates, also depicts the crucial discoveries (vertical lines) and is easy to grasp. Evidently, the interpretation of the development is provided during the non-linear lecture.

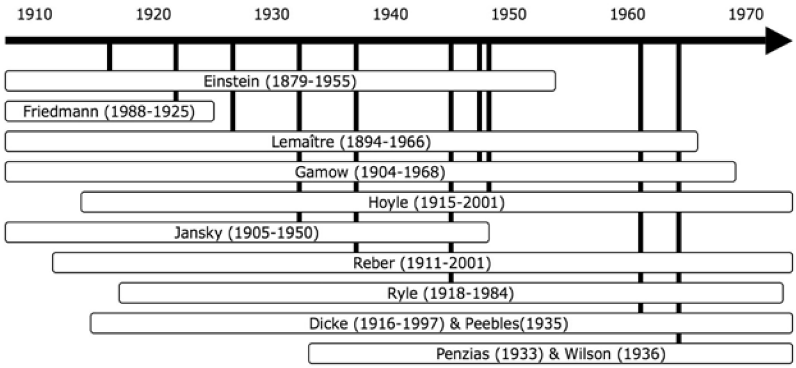

Figure 11: *A two-dimensional timeline for ERA, introducing the scientists and marking their main discoveries or theories, as addition to a non-linear account*

If several non-linear accounts are given by the same lecturer on the same discipline, e.g. cosmology, it is likely that redundancy occurs. ERA will overlap partially with the history of CBR, relativity theory, quantum cosmology, etc. That should not be seen as a disadvantage, on the contrary. It will help students to bring all topics more closely together and will give them at least a feeling of understanding through reminiscence.

Testing non-linearity

To prove the surplus value and efficiency of non-linear teaching, the idea will be tested in a classroom setting. Linear teaching is the threshold here. The hypothesis under investigation is formulated as follows: *non-linear teaching of history leads to a better understanding of history for all learning styles*. Two research questions emerge: (1) *does non-linear teaching of history improve study results as a measure for better understanding?* and (2) *is there a significant difference related to learning styles?* Three groups of students follow respectively an exclusively linear presentation, an exclusively non-linear presentation and a hybrid presentation on the same topic by the same lecturer. Before the lectures take off, the learning styles of the subjects are determined. A zero-measurement of the knowledge on the topic precedes the lectures. The students are identically questioned on the topic immediately after the lecture (measuring comprehension).

A lecture takes one class period (about 45 minutes). The trials are scheduled for February 2011-May 2011. In two secondary schools two runs will be held (two teachers, two topics, six groups, about 120 students)[10] and two runs as well at college level (two professors, two topics, six groups, about 110 students).[11]

10 Iris Gysels and Stefan Joosten, both holding a master's degree in history.
11 Jean Paul Van Bendegem and Bart Van Kerkhove, both holding a doctoral degree in philosophy (of science).

For the college students the topics are "scientific methodology from a historical point of view" and "philosophy of science from a historical point of view". The topics for the secondary schools depend on the subject the teachers have to cover at that time (for example, "the Cold War"). These topics do belong to the study curriculum, but for ethical reasons the content will not be subject to examination (otherwise the students that take part are privileged and I evidently expect a significant difference in outcome).

Learning styles are an altogether different story. There are as many definitions and consequently learning-style inventories, as there are researchers in that domain (Cassidy 2004). For the study in hand, it suffices to define learning styles as particular methods of dealing with information. Each individual will apply a certain learning style when confronted with subject material. Vermunt (1998) identified four learning styles: reproduction-directed (RD), meaning-directed (MD), application-directed (AD) and undirected (UD). This validated inventory will be used as system for the project in question. The outcome of the trials will show which learning styles will benefit by non-linear teaching (hopefully they all will). Presumably, RD will profit from the linear account, MD, AD and UD gain the most from the (strict) non-linear approach. I expect all students to benefit by the hybrid method. Additional research can be performed to find out whether the supply of a timeline makes any difference in efficiency of learning.

Implications

There is an alternative to traditional linear accounts of the history of science. Chronologies do have their merit, but they hardly serve open, adequate and efficient learning. It is argued that a linear overview is necessary, but insufficient. A non-linear approach promises to be more suitable. However, to optimize understanding, a timeline needs still to be provided as a supplement to an extensive and core non-linear account.

I hope that at least a fruitful discussion emerges out of this paper. Evidently, if the trials indicate a positive influence of non-linearity on didactics, this new model will be extensive in influence too.

Acknowledgement
I want to express my thanks to Ian Kinchin, Assistant Director of King's Learning Institute, King's College London, for his advise on research design and for sending me his recent articles.

References

- Basilakos, S., Plionis, M., and Solà, J. (2009), "Hubble expansion and structure formation in time varying vacuum models", *Physical Review D* 80(8): #083511.
- Cassidy, S. (2004), "Learning styles: An overview of theories, models, and measures", *Educational Psychology* 24: 419-444.
- Cornelis, G.C. (1998), "Is popularisation of science possible?", [html] *Twentieth World Congress of Philosophy*. Available at: http://www.bu.edu/wcp/Papers/Scie/ScieCorn.htm [Accessed 24 August 2010].
- Cornelis, G.C. (2000), *Zoeken naar oplossingen* (*Looking for solutions*). Brussels: VUBPress.
- Cornelis, G.C. (2009), "Passive media serving diverse learning styles", *Proceedings of the 14th Annual Conference of the European Learning Styles Information Network*, 163-271.
- Dewey, J. (1910), *How we think*. Boston: DC Heath.
- Eddington, A. ([1933] 1987), *The Expanding Universe*. Cambridge: Cambridge University Press.
- Einstein, A. (1917), "Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie", *Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften:* 142-152.
- Hacking, I. (1981), "Imre Lakatos's Philosophy of Science", in Hacking, I. (ed.), *Scientific Revolutions*. Oxford: Oxford University Press.
- Kinchin, I.M., Cabot, L.B. (2007), "Using concept mapping principles in PowerPoint", *European Journal of Dental Education* 11: 194-199.
- Kinchin, I.M., Chadha, D., Kokotailo, P. (2008), "Using Powerpoint as a lens to focus on linearity in teaching", *Journal of Further and Higher Education* 32: 333-346.
- Kinchin, I.M. (2009), "Influencing learning styles with teaching strategies: A knowledge structures perspective", *Proceedings of the 14th Annual Conference of the European Learning Styles Information Network*, 268-275.
- Kinchin, I.M., Cabott, L.B. (2010), "Reconsidering the dimensions of expertise: from linear stages towards dual processing", *London Review of Education* 8(2): 153-166.
- Knobloch, E. (2006), "Alexander von Humboldt: The explorer and the scientist", *Proceedings of the 2nd ICESHS*, 38-48.
- Latour, B. (1987), *Science In Action: How to Follow Scientists and Engineers Through Society*. Cambridge: Harvard University Press.
- Southword, G.C. (1956), "Early History of Radio Astronomy", *Scientific Monthly* 82: 55-66.
- Sullivan, W.T. ([1984] 2004), *The Early Years of Radio Astronomy*. Cambridge: Cambridge University Press.
- Tiwari, R.K., Rahaman, F., Ray, S. (2010), "Five Dimensional Cosmological Models in General Relativity", *International Journal of Theoretical Physics* 49: 2348-2357.
- Vermunt, J. (1998), "The regulation of constructive learning processes", *British Journal of Educational Psychology* 68: 149-171.