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Rhetoric of science: Fixed and changing modes of scientific discourse

Abstract: The paper identifies ten types of arguments that are found to run through time when scientist-writers address a mixed audience of literate people, apprentices and experts alike. The rhetoric of science is argued to be a useful exploratory means to develop understanding of scientific cultures and specialized discourses, as well as promote apprenticeship into the sciences.

1. Introduction: On the rhetoric of science

To explore the relationship between rhetoric and knowledge, I take scientific knowledge as the central issue and look at rhetoric of science as an opportunity of enculturation into specialized communication, a way into the gradual and systematic acquisition of the characteristics and norms of scientific and technical cultures by novices and experts alike. It is therefore the transfer of knowledge and apprenticeship into science that is the focal point of the present contribution.

My concern is primarily pedagogical to the extent that I believe rhetoric of science can be used as an empowering educational tool to promote advanced literacy and improve communication skills through a deeper understanding of scientific reasoning and 'epistemic cultures' (Knorr-Cetina 1999). A rhetorical approach to science can help to train new experts to perfect their literacy skills, while at the same time progressing with analytical knowledge of specialized discourse in the various genres of communication (see, for example, Bazerman 1988; Bazerman and Prior 2004; Berkenkotter and Huckin 1993). It can help us become better practitioners of science while becoming better practitioners of rhetoric. This seems all the more necessary in the present day knowledge society characterized by global access to information and where knowledge may be co-constructed to improve the human condition (see Greco 2007; Vallima and Hoffman 2008).

Consequently, the approach that is proposed in the central section of this paper is aimed at reconstructing arguments in texts in the belief that analysis and exposition of scientific argumentation need to be firmly grounded in extensive illustration from original texts in order to have a pedagogical value. This is not so different from allowing that knowledge is rhetorical and conceiving of rhetoric "as a necessary and integral part of the engaged practice of science itself" (Gottschalk Druske 2014: 2). It is in line with other proposals from within argumentation studies aiming to find a place for rhetoric in the construction, discovery and learning of science (notably Buty, Plantin 2009 on rhetoric in science education) and with the rhetoric of enquiry turn in the American tradition as summarized in Lyne and Miller (2009) and represented, among others, by the many contributions in Gross and Keith (1997).

It is thus useful to take some complementary definitions of rhetoric of science, which together justify the place of rhetoric in science studies. Finocchiaro (2005: 329) defines rhetoric of science as "…the critical understanding of actual reasoning"; Fahnestock (1999: 43) as "…attention to arguments from past and current scientific texts and controversies" and Gaonkar (1997: 25) as "a way of reading the endless discursive debris that surrounds us." Finally, and from a more radical perspective, Gottschalk Druske (2014) writes that:

> rhetoric offers a useful perspective on the scientific endeavor; rhetoric complicates and contextualizes the practice of science and its translation into policy; rhetoric adds necessary – even ethical – depth, complication, and nuance to the communication of scientific results and to perspectives on public engagement with science. (Gottschalk Druske 2014: 4)

All definitions owe to the legacy both of Perelman and Olbrecht-Tyteca's (1958) *Traité de l'argumentation* and Toulmin's (1958) *Uses of Argument*, particularly in regard to the emphasis on situated analyses of reasoning practices and the need for context-sensitive theories of knowledge.

2. Types of argument in scientific discourse

In this section I run through a number of arguments, which appear to be typical of scientific discourse irrespective of historic time, field of enquiry and scientist-writer. These are forms of argument that resist change and keep coming back as constants of scientific reasoning. I should point out that I use the term 'argument' in its loosest sense of 'argumentation, lines of reasoning, rhetorical devices,' and that I am fundamentally interested in the phrasing that such arguments display, their linguistic shape, linguistic and discursive formations of science being the main focus of the present contribution.

The list of arguments contains ten types: Thought experiments; Real experiments; Argument by illustration and example; Reasoning by analogy; Appeal to emotions (*pathe*); Digression as argument; Historicization and narrativization; Formal logic; Series reasoning; Grammatical metaphor.

Table 1 below offers an overview of the scientists and texts that I have selected to identify recurrent modes of argumentation, in chronological order. However, the diverse reasoning lines are exemplified allowing some freedom to jump from one case to the next disregarding vicinity in time or disciplinary affinity. For each scientist and text short title, the domain and topic are specified and an attempt is made at defining the genre also on the basis of the audience addressed. The date reported is the date of publication, so that in the case of lectures it corresponds to the year when the transcribed and edited versions were first published as books.

Table 1. List of scientific texts exemplified

SCIENTIST	DOMAIN	TEXT	DATE	TOPIC	AUDIENCE	GENRE
Galileo Galilei	Mechanics	Discourses on Two New Sciences	1638	Mechanics of materials and motion of bodies	Wide	Treatise
Charles Darwin	Biology / Natural Sciences	Origin of Species	1859	Natural selection	Wide	Treatise
Michael Faraday	Chemistry	Chemical History of a Candle	1861	Laws of combustion	Juvenile	Lectures
Charles Darwin	Biology / Anthropology	Descent of Man	1871	Origin of man	Wide	Treatise
Richard Feynman	Mechanics / Electromagnetism	Lectures on Physics (Six Easy Pieces)	1963	Laws of classical physics	University undergraduates	Lectures
John D. Barrow	Mathematics / Astrophysics	Infinities	2002	Infinity	Wide	Play
Mark Miodownik	Mechanics	Size Matters	2010	Mechanics of materials	Juvenile	Lectures

2.1 Thought experiments

The first two types of argument to be considered are thought experiments and the *argumentum ad absurdum.*

Thought experiments are understood as hypothetical situations imagined by the scientist for the purpose of thinking through the consequences of the experiment, whether it is possible to actually perform it or not (see Brown 2011; Frappier *et al.* 2013). Linguistically, they are usually introduced by verbs such as *suppose* or *imagine* and *if*-clauses with the *irrealis* mood. Often, though not necessarily, the thought experiment appears together with the argument *ad absurdum*, signaled by *otherwise* (in English) introducing an incongruous conclusion.

Perhaps the most illuminating example of a thought experiment containing the *argumentum ad absurdum* is to be found in Day I of the *Two New Sciences*. In what is considered the founding book of modern experimental science, Galileo proves wrong Aristotle's notion that bodies of different weights fall to the ground at different speeds, with heavier bodies being faster and lighter bodies being slower. This is an often cited thought experiment in the literature (cf. Kuhn 1977; Finocchiaro 2005; Brown 2011). However, because of its absolute clarity it is worth analyzing here. Together with the Italian original, the English translation by Henry Crew and Alfonso De Salvio is provided.

Galileo has Salviati imagine that we combine bodies of different weight together and drop them from a height. Following Aristotle's premise, the experiment allows for two perfectly logical yet mutually opposed conclusions: either the two bodies combined are faster because the combination of the two is heavier than the heavier weight, or they fall at an intermediate velocity because the heavier body accelerates the slow one, but the light body slows down the heavier one. Based on the same premises, therefore, two contradictory conclusions follow. Hence, Aristotle must be wrong, *otherwise* one ends up accepting two logical, yet mutually exclusive, conclusions.

In the following long extract, the lexemes supporting the thought experiment *quando-se* 'If,' *suppor-supposizione* 'assumption, supposition,' *fusse* 'would be,' *concludete pertanto che* 'therefore conclude that,' *per ciò* 'therefore,' etc. (in italics in the text) mark an intricate argumentative development dialogically shaped between Salviati and Sagredo and tightly paced, leading to the conclusion that all bodies fall with the same speed; see extract (1):

(1) *Two New Sciences*

It.

SALV. *Quando* dunque noi avessimo due mobili, le naturali velocità de i quali fussero ineguali, *è manifesto che se* noi congiugnessimo il più tardo col più veloce, questo dal più tardo sarebbe in parte ritardato, ed il tardo in parte velocitato dall'altro più veloce. *Non concorrete voi meco in quest'opinione?*
SIMP. *Parmi che così debba indubitabilmente seguire.*

SALV. *Ma se* questo è, ed è insieme vero che una pietra grande si muova, per esempio, con otto gradi di velocità, ed una minore con quattro, adunque, congiugnendole amendue insieme, il composto di loro si moverà con velocità minore di otto gradi: ma le due pietre, congiunte insieme, fanno una pietra maggiore che quella prima, che si moveva con otto gradi di velocità: adunque questa maggiore si muove men velocemente che la minore; *che è contro alla vostra supposizione.* Vedete dunque come *dal suppor che* 'l mobile più grave si muova più velocemente del men grave, *io vi concludo*, il più grave muoversi men velocemente.

SIMP. *Io mi trovo avviluppato*, perché mi par pure che la pietra minore aggiunta alla maggiore le aggiunga peso, e aggiugnendole peso, non so come non debba aggiugnerle velocità, o almeno non diminuirgliela.

SALV. *Qui commettete un altro errore*, *Sig. Simplicio*, perché non è vero che quella minor pietra accresca peso alla maggiore.
SIMP. *Oh, questo passa bene ogni mio concetto*.

SALV. *Non lo passerà altrimente*, *fatto ch'io v'abbia* accorto dell'equivoco nel quale voi andate fluttuando: [..] *Concludete pertanto che* nella libera e naturale caduta la minor pietra non gravita sopra la maggiore, ed *in consequenza* non le accresce peso, come fa nella quiete.
SIMP. *Ma chi posasse* la maggior sopra la minore?

SALV. Le *accrescerebbe* peso, *quando* il suo moto *fusse* più veloce: *ma già si è concluso che quando* la minore *fusse* più tarda, ritarderebbe in parte la velocità della maggiore, *tal che* il loro composto *si moverebbe* men veloce, essendo maggiore dell'altra; *che è contro al vostro assunto. Concludiamo per ciò, che* i mobili grandi e i piccoli ancora, essendo della medesima gravità in spezie, si muovono con pari velocità. (Giornata I)

Eng. tr.

SALV. *If then* we take two bodies whose natural speeds are different, *it is clear that* on uniting the two, the more rapid one will be partly retarded by the slower, and the slower will be somewhat hastened by the swifter. *Do you not agree with me in this opinion?*
SIMP. *You are unquestionably right.*

SALV. *But if* this is true, *and if* a large stone moves with a speed of, say, eight while a smaller moves with a speed of four, *then* when they are united, the system will move with a speed less than eight; but the two stones *when* tied together make a stone larger than that which before moved with a speed of eight. *Hence* the heavier body moves with less speed than the lighter; an effect which is *contrary to your supposition*. Thus you see how, *from your assumption that* the heavier body moves more rapidly than the lighter one, *I infer that* the heavier body moves more slowly.
SIMP. *I am all at sea* because it appears to me that the smaller stone when added to the larger increases its weight and by adding weight I do not see how it can fail to increase its speed or, at least, not to diminish it.

SALV. *Here again you are in error*, *Simplicio*, because it is not true that the smaller stone adds weight to the larger.
SIMP. *This is, indeed, quite beyond my comprehension*.

SALV. It will *not be beyond you when* I have once shown you the mistake under which you are laboring. [..] *You must therefore conclude that*, during free and natural fall, the small stone does not press upon the larger and *consequently* does not increase its weight as it does when at rest.
SIMP. *But what if we should* place the larger stone upon the smaller?

> SALV. Its weight *would be* increased *if* the larger stone moved more rapidly; *but we have already concluded that when* the small stone moves more slowly, it retards to some extent the speed of the larger, *so that* the combination of the two, which is a heavier body than the larger of the two stones, *would move* less rapidly, *a conclusion which is contrary to your hypothesis. We infer therefore that* large and small bodies move with the same speed provided they are of the same specific gravity. (Day I)

According to Kuhn (1977) thought experiments like this one, in bringing about a deeper understanding of the conceptual apparatus of the scientist by eliminating ambiguities and contradictory positions, also lead to a new understanding of natural phenomena.

More than 300 years later, Richard Feynman, Professor of Theoretical Physics at the California Institute of Technology and 1965 Nobel Prize winner, uses thought experiments at various points in his argumentation on mechanics and electromagnetism. An example can be found in his *Lectures on Physics*, an introductory physics course to freshmen and sophomores that he was asked to teach at Caltech in the early 1960s, later transcribed and edited for publication to become *The Feynman Lectures on Physics*. A part of it was subsequently published as *Six Easy Pieces. The Fundamentals of Physics Explained.*

In the following thought experiment, Feynman illustrates the complex principle of the conservation of energy, whereby "there is a certain quantity, which we call energy, that does not change in the manifold changes which nature undergoes," "a most abstract idea, because it is a mathematical principle" (Feynman 1995: 69). He limits the illustration to one form of energy, namely gravitational potential energy (whose formula is weight times height).

It is in this context that a thought experiment is introduced, linguistically marked by the verb *imagine*, activating the imaginary scenario of the reversible weight-lifting machine in which no energy is lost and perpetual motion is attained. The whole thought experiment is built on this idealization, demonstrating that in an ideal machine energy is conserved. The argument construes a contrast with real-life non-reversible machines, showing that these cannot perform better than the reversible machine because they would create perpetual motion, which is an impossibility. I have added the italics to highlight the forms of the verbs *imagine*, *suppose*, *deduce* supporting the argument and the irrealis *would* marking hypothetical-deductive reasoning.

(2) *Six Easy Pieces*

> *We imagine that* there are two classes of machines, those that are not reversible, which includes all real machines, and those that are reversible, which of course are actually not attainable no matter how careful we may be in our design of bearings, levers, etc. *We suppose, however, that* there is such a thing, a reversible machine,

> which lowers one unit of weight (a pound or any other unit) by one unit of distance, and at the same time lifts a three-unit weight. Call this reversible machine, Machine A. *Suppose* this particular reversible machine lifts the three-unit weight a distance X. *Then suppose* we have another machine, Machine B, which is not necessarily reversible, which also lowers a unit weight a unit distance, but which lifts three units a distance Y. *We can now prove that* Y is not higher than X; that is, *it is impossible* to build a machine that will lift a weight any higher than it will be lifted by a reversible machine. Let us see why. *Let us suppose that* Y were higher than X. We take a one-unit weight and lower it one unit height with Machine B, and that lifts the three-unit weight up a distance Y. *Then we could* lower the weight from Y to X, obtaining free power, and use the reversible Machine A, running backwards, to lower the three-unit weight a distance X and lift the one-unit weight by one unit height. This will put the one-unit weight back where it was before, and leave both machines ready to be used again! *We would therefore* have perpetual motion if Y were higher than X, which we assumed was impossible. With those assumptions, *we thus deduce that* Y is not higher than X, so that of all machines that can be designed, the reversible machine is the best. (*Six Easy Pieces*, pp. 73–74)

Unlike the first example, the function of the thought experiment in (2) is illustrative rather than probative. It is not used to refute a theory, but to clarify what is meant by one particular law, i.e., conservation of energy.

Both extracts lead us onto another fundamental type of argument in the history of modern scientific reasoning, that of abstraction and simplification accompanying real experiments. It should be noticed, for instance, that in (1) air resistance is an auxiliary phenomenon that ought to be abstracted from when experimenting, so as to reach a generalization.

2.2 Real experiments

Real experiments are reported by scientists as a means of proof and a most effective way to produce new knowledge, and sometimes are even performed in front of their audiences, to stress the importance of seeing what happens, of observing and possibly replicating the experiments. Indeed experiments that have been carried out populate the *Two New Sciences*, as can be seen in the following selection of concordances of the words *esperienza/-e* (Fig. 1). The concordances point to various places in the dialogue where Salviati refers to experiments he has conducted, as for example when he uses an inclined plane to observe gravitational acceleration and reproduce a situation practically rid of any resistance of the medium.

Figure 1. Concordances of esperienza/esperienze *from the* Two New Sciences

mento dell'aria grave, facendomelo veder con	**l'esperienza,**	se nel venire alla prova ei mi dicesse: «Piglia
n tal ragione ha osservato l'arte, e confermato	**l'esperienza,**	che un'asta vota o una canna di legno o di metal
. SAGR. Il discorso mi par concludentissimo, e	**l'esperienza**	tanto accomodata per verificare il postulato, che
ella luce non poter esser se non velocissima: e	**l'esperienza**	che mi sovvenne, fu tale. Voglio che due piglino
vano nell'istesso tempo; voi trovate, nel farne	**l'esperienza,**	che la maggiore anticipa due dita la minore, cio
grave; or quel vedersi accenna l'averne fatta	**l'esperienza.**	
consequenza la propensione di andare in su: ma	**l'esperienza**	mostra l'opposito. Quanto all'altra domanda, che
momento acquistato per la scesa CB, come mostra	**l'esperienza;**	adunque tutti i momenti che si acquistano per le
rienza assicurarci qual ella sia? SIMP. Mostra	**l'esperienza**	quotidiana, l'espansion del lume esser instantane
l'istesso mobile. Quanto al primo, il mostrarci	**l'esperienza**	che due palle di grandezza eguali, ma di peso l'u
quarta, ciò di novanta gradi, mostra parimente	**l'esperienza,**	passarsi tutti in tempi eguali, ma però più brev
etto, ci dimostra l'Autore quello che forse per	**l'esperienza**	non è stato osservato: e questo è, che de gli alt
mamente esser la metà dell'altro: e facendo poi	**l'esperienze**	di altre parti, esaminando ora il tempo di tutta
itrova, assai concludente argomento ce ne porge	**l'esperienza**	del pallone gonfiato, posta da Aristotele; perch
Ma con esso noi, lontani da simili pretensioni,	**l'esperienze**	e le ragioni sin qui addotte bastano a quietarci:
ell'aria resterei nel medesimo dubbio di prima.	**L'esperienza,**	dunque, di Aristotele buona, e la proposizion
allora altrettanto più veloce il sughero? e pur	**l'esperienza**	mostra ciò avvenire. Però notate: slargato il pen
8, 4, ed anco di 2 e di 1: ma a questo repugna	**l'esperienza;**	imperò che se due compagni si metteranno a numer
nella quale ben poi sempre si mantenga. SAGR.	**L'esperienze**	veramente mi par che siano molto a proposito; n
mati potranno esser commodamente veduti. SAGR.	**L'esperienza**	mi pare d'invenzione non men sicura che ingegnosa
efficaci, le sentiremo molto volentieri. SALV.	**L'esperienza**	fatta con due mobili quanto pi si possa differen
mossi; ed il rimuoverla fu effetto della medesima	**esperienza**	che di presente a voi la suscita. Voi dite, parer
notabile velocità; ed io dico che questa medesima	**esperienza**	ci chiarisce, i primi impeti del cadente, bench
. SAGR. Eh, Sig. Simplicio, da cotesta notissima	**esperienza**	non si raccoglie altro se non che il suono si con
a natura ed al vero, con ragioni o osservazioni o	**esperienze**	tritissime e familiari ad ogn'uno, ha (come da di
rci: tuttavia, quando abbiate altre più palpabili	**esperienze**	e ragioni più efficaci, le sentiremo molto volent
in conclusione con qualunque altra divisione, per	**esperienze**	ben cento volte replicate sempre s'incontrava, gl
pposizioni incostanti possano poi nelle praticate	**esperienze**	verificarsi. SALV. Tutte le promosse difficoltà
e stato opportuno in questo luogo arrecar qualche	**esperienza**	di quelle che si è detto esservene molte, che in
o dire, in confermazione dell'esattezza di questa	**esperienza**	ed insieme per chiara prova della nulla resistenz
e il chiodo e se gli avvolgerebbe intorno. Questa	**esperienza**	non lascia luogo di dubitare della verità del sup
e altrui attestazioni, ed anco da molte replicate	**esperienze.**	SALV. V. S. molto veridicamente discorre: e la
entamente, ferma certezza ce ne porge la seguente	**esperienza.**	Sospendansi da due fili egualmente lunghi, e di

Experiment and abstraction are even more carefully dealt with in modern science than in Galileo. A significant example is offered by another great scientific figure and a classic work of popular science, namely *The Chemical History of a Candle.*

The *Chemical History* is a block of six talks delivered by Michael Faraday in 1860 at the Royal Institution of Great Britain in London as part of a series of Christmas lectures for a juvenile audience he started in 1825. Faraday was indeed an engaging communicator of science and helped establish the tradition of scientific popularization that forms part of science vocation in Britain. Of the 19 series of lectures Faraday gave, perhaps the most famous one was on the candle, later published as a book, indeed one of the most successful science books ever published (James 2007, 2011).

Faraday makes many experiments before his audience, as indicated by the many instances of *Here you see, You see these, You see there, You observe, You see I have shown, You will see, You will notice, You may see* and *Which you can look at … and carefully examine…* and is well aware of experimental conditions in the laboratory to reduce error, as exemplified by the extracts in (3); see the italicized words *regularity*, *simplify*, *difficulties in the way*, *imitate* pointing to the experimental situation and the various actions performed by the scientist in the lab, e.g., *by applying*, *by placing*, with the aim of proving the laws of combustion:

(3) *Chemical History of a Candle*
We have here a good deal of wind, which will help us in some of our illustrations, but tease us in others; for the sake, therefore, of *a little regularity*, and *to simplify* the matter, *I shall make a quite flame, for who can study a subject when there are difficulties in the way not belonging to it?* (Lecture I, p. 6)

Now I am going to imitate the sunlight *by applying* the voltaic battery to the electric lamp. *You now see* our sun, and its great luminosity; and *by placing* a candle between it and the screen, we get the shadow of the flame. *You observe* the shadow of the candle and of the wick; (Lecture I, p. 13)

I suppose some here will have made for themselves the experiment I am going to show you. Am I right in supposing that anybody here has played at snapdragon? I do not know a more beautiful illustration of the philosophy of flame, as to a certain part of its history, than the game of snapdragon. First, here is the dish; and let me say, that when you play snapdragon properly you ought to have the dish well warmed; you ought also to have warm plums, and warm brandy, which, however, I have not got. When you have put the spirit into the dish, you have the cup and the fuel; and are not the raisins acting like the wicks? I now throw the plums into the dish, and light the spirit, and *you see* those beautiful tongues of flame that I refer to. (Lecture I, p. 15)

In the last example, Faraday refers the familiar habit of firing plums and raisins with brandy for Christmas and enacts it to explain combustion to his young auditory. This is just one of a large set of experiments that confer vividness and clarity to the chemical explanations of his lectures.

Perhaps one of the most famous experiments ever conducted in front of a wide audience was Feynman's showing on television a piece of gasket material becoming rigid when dropped in a cup of ice water to explain why the space shuttle Challenger had tragically exploded: the gasket material had lost its ability to seal, just as the O-rings on the Challenger's rocket booster joints; see the extract from the televised hearing of the Presidential Commission on the Space Shuttle Challenger Accident, February 1986:

(4) *On the Space Shuttle Challenger Accident*
I took this stuff that I got out of your seal and *I put* it in ice water, and *I discovered that when you put* some pressure on it for a while *and then undo* it, it doesn't stretch back, it stays the same dimension. In other words, for a few seconds at least, and more seconds than that, there is no resilience in this particular material when it's at a temperature of 32 degrees. *I believe* that has some significance for our problem.

The italics underlines the verbs and subject pronouns expressing the scientist's experimental procedures aimed at showing what had happened and how a fundamental law of physics had been disregarded in the design of the shuttle.

2.3 Argument by illustration and example

Another recurrent argumentative device in scientific discourse is argument by illustration and example. *The Royal Institution Christmas Lectures* offer again a case in point. With the only break during World War II, the *Christmas Lectures* have been running yearly and are now a popular British event broadcast by the BBC every year, dedicated to connecting the lay-public, especially young people, with the world of science. The aim is to establish continuity with the long-standing tradition inaugurated by Faraday in the 19^{th} century and possibly also to promote a recruitment policy in the UK that tries to increase the number of young men and women pursuing a career in the sciences.

In 2010 the lecture was delivered by materials scientist and University College London professor Mark Miodownik, and it concerned the mechanics of materials, informally referred to as 'stuff' by the scientist (notice incidentally the use of *stuff* by Feynman in the previous example), and one of the two new sciences expounded by Galileo in his *Discourses*.

Miodownik's lecture is particularly representative of this type of scientific reasoning that makes use of a vast array of examples to explain a topic of the mechanics of materials, specifically static and dynamic pressures, i.e., the physical concept of the area to volume (i.e., weight) ratio in bodies. The idea, which was first explained by Galileo, is that if a body is increased in size, while maintaining the proportion of all its parts, it does not get stronger per weight, contrary to what common-sense thinking would make one think (the bigger, the stronger).

The reason for that is explained again in the *Two New Sciences*, where Galileo highlights the importance of area to weight ratio. Larger bodies are less strong than smaller ones because the area gets smaller compared to the volume it supports. Galileo shows that pressure is proportional to height, thus, when keeping the same proportions, i.e., without changing the design, a higher body is subject to a heavier pressure. If we double the size of a body, and keep the same design, the pressure it exerts is twice as much (the weight grows by 8 times and the area by 4 times). Otherwise, using Miodownik's wording, "when you size things up the area to volume ratio changes" (*Size Matters*, 43' 29").

In watching Miodownik's lecture, what is apparent is a process of recontextualization of the same illustrations offered by Galileo alias Salviati in the *Discourses*. The vast number of cases which were described by Galileo, sometimes accompanied by drawings, including the falling horse that breaks its bones unlike a falling dog or cat that do not, the grasshopper falling from a tower and an ant falling from the moon, Ariosto's giants, a dog holding another dog, a horse that cannot hold another horse, the bones of the whale, etc., are all reused and recontexualized with the help of the televisual media affordances to help explain a counterintuitive notion to an audience of non-experts.

The examples that Galileo chose for Simplicio and the kind of common-sense thinking the latter is a spokesman for also work very well with this 21st-century audience. Thus, Miodownik's 'crash test hamster Amish' and 'crash test dog Sweep' replace horses, cats and dogs, fuelling empathy if not compassion on the children's audience. Similarly, Gordon the gecko and the reference to Spiderman climbing up walls are used to exemplify friction, the dancers from the TV programme *Strictly Come Dancing* and the strongest man we know ("what are your strength credentials?," asks the scientist and "could you just give us a demonstration of exactly how strong you are?") who can lift up to slightly more than 2 times his weight, whereas a lighter man can lift up to more than 3 times his weight, replace Ariosto's giants. Visuals work as effective and entertaining explanations (Fig. 2).

Figure 2. A screenshot from the Ri Christmas Lecture 2010

Argument by illustration and example leads me on to another two types of reasoning, the first having to do with the argumentative difference between illustrations and analogies, i.e., reasoning by analogy. The second deals with a dimension already identified by Aristotle as the orator's appeal to emotions (*pathe*), namely the reliance on the part of the orator on the audience's non-rational frame of mind, their preconceptions, values and assumptions in order to obtain persuasion.

2.4 Reasoning by analogy

Although devoting little space to the sciences, Perelman and Olbrechts-Tyteca's model of analogical reasoning might come in handy to analyze the language used by scientists to build analogies.

The *Traité de l'argumentation* considers analogy as an essential factor of invention as well as a means of proof to the extent that the audience might be led to prefer one hypothesis over another (see in particular Perelman and Olbrechts-Tyteca 1969: 371 ff.). In the authors' view, the argumentative function of analogies is triggered by the structural similarity between two terms which they call the 'theme,' or the focal point of the line of reasoning, and the 'phoros,' namely the starting point of the argument, with which the audience usually has more familiarity than the theme. In virtue of the resemblance between phoros and theme and of the comparison established through the analogy, the theme becomes clearer. Accordingly, the theme and the phoros must come from different knowledge fields and it is because of a sense of separate spheres or incommensurate arenas that reasoning by analogy becomes particularly useful. In science analogy can serve as a link in the chain of inductive reasoning, and certainly has an elucidatory function in contexts of knowledge transfer.

It is again Feynman's *Lectures on Physics* that well exemplify analogical reasoning, and the already mentioned chapter on "Conservation of Energy," where perhaps the most brilliant analogy of the whole collection is to be found. To explain the meaning of this abstract concept the physicist uses an extended analogy that is reported below in the extract in (5). The same verbs that have been said to introduce thought experiments, *imagine* and *suppose*, here introduce the phoros, the playful and familiar situation of the Lego blocks, while the transition to the theme is indicated by the word *scheme* and its quantitative features, ultimately condensed in the two formulas in (4.1) and (4.2) and in the conclusion that we do not know what energy is and yet we can calculate it.

(5) *Six Easy Pieces*
Imagine a child, perhaps "Dennis the Menace," who has blocks which are absolutely indestructible, and cannot be divided into pieces. Each is the same as the other. *Let us suppose* that he has 28 blocks. His mother puts him with his 28 blocks into a room at the beginning of the day. At the end of the day, being curious, she counts the blocks very carefully, and discovers a phenomenal law – no matter what he does with the blocks, there are always 28 remaining! This continues for a number of days, until one day there are only 27 blocks [..] Another day, careful count indicates that there

> are 30 blocks! This causes considerable consternation, until it is realized that Bruce came to visit, bringing his blocks with him, and he left a few at Dennis' house. [..] Being extremely curious, and somewhat ingenious, she invents a *scheme*! She knows that a block weighs three ounces, so she weighs the box at a time when she sees 28 blocks, and it weighs 16 ounces. The next time she wishes to check, she weighs the box again, subtracts sixteen ounces and divides by three. She discovers the following:
>
> (number of blocks seen) + [(weight of box) – 16 ounces] / 3 ounces = constant. (4.1)
>
> [..] *this new formula* would be:
>
> (number of blocks seen) + [(weight of box) – 16 ounces] / 3 ounces +
> (height of water) – 6 inches/ ¼ inch = constant. (4.2)
>
> [..] *As a result*, she finds *a complex formula*, a quantity which has to be computed, which always stays the same in her situation. (*Six Easy Pieces*, pp. 70–71)

In the *Chemical History*, analogies are drawn from the outside world, they are often extraneous events like carbon dioxide in London (Lecture VI, p. 93) which help understand the subject and at the same time confer spontaneity to the lectures.

Analogical reasoning can be found also in a different knowledge field, biology, and major work, namely Charles Darwin's *Origin of Species*. The great naturalist argues his case from analogy, whereby variations occurring under domestication must apply to variations occurring in nature. An inference is constructed on the analogy, 'if under domestication, so in a state of nature' (cf. also Fahnestock 1999).

2.5 Appeal to emotions

This appears to be combined with dramatization and entertainment value, which is evident in the more modern cases analyzed, but significantly already in the *Two New Sciences*.

First and foremost, Galileo's choice to use fictive dialogue among the three participants, Salviati, Sagredo, Simplicio, confers to his demonstrations a kind of liveliness which is not so dissimilar from the engaging mood of the lectures for a juvenile audience employed both by Faraday and Miodownik and from Feynman's entertaining analogies in *Six Easy Pieces*.

While making the reasoning process explicit by dramatizing the scientist's interior monologue, the dialogic form also reflects the need to adapt expert discourse for a lay audience; it accommodates a plurality of voices and opinions, so it is inherently dialectic and open to engagement on the part of the readership, similar to a 'conversation between friends,' as in the English translation below (see among others Altieri Biagi 1983; Zanarini 1983; Raimondi 2002).

Moreover, Galileo uses irony with Simplicio who is often confused with doubts (*dubbi* in the original Italian text). Doubts are crucial, as can be seen in the following extract, but sometimes irony prevails:

(6) *Two New Sciences*

It.

SAGR. Di grazia, godiamo del benefizio e privilegio che s'ha dal parlar con i vivi e tra gli amici, e più di cose arbitrarie e non necessarie, differente dal trattar co' i libri morti, li quali ti eccitano mille dubbi e nissuno te ne risolvono. [..] ed in particolare i dubbii toccati dal Sig. Simplicio non si trapassino in tutti i modi. (Giornata I)

Eng. tr.

SAGR. Pray let us enjoy the advantages and privileges which come from *conversation between friends*, especially upon subjects freely chosen and not forced upon us, a matter vastly different from dealing with dead books which give rise to many doubts but remove none. [..] and in particular the objections raised by Simplicio ought not in any wise to be neglected. (Day I)

Faraday's experiments discussed above have an important function in dragging down the subject and appealing to the audience in a very direct manner (see James 2011). He refers to everyday events the audience is already familiar with (e.g. snapdragon) to create a lively and engaging atmosphere.

This is replicated by Miodownik, whose present-day lecture makes use of as much spectacularization as the technological and visual affordances of TV allow him to and are filled with humor. He makes jokes to entertain youngsters and adults alike. See the example in (7) below, where the scientist introduces some of the properties of materials:

(7) *Size Matters*

Now, liquids and mobile phones, they don't really mix, do they? Anyone who's ever sat down on the loo with their phone in the back pocket and heard a splash knows this! (*Size Matters*, 01' 49")

An interesting example of the appeal to emotions in dealing with complex scientific contents is offered by John D. Barrow's theatrical play about the mathematical notion of infinity. *Infinities* opened at Bovisa Warehouses in Milan in 2002, after being commissioned by the Piccolo Teatro and his artistic director Luca Ronconi to Cambridge professor of mathematics and physics John D. Barrow, who is actively engaged in the public understanding of science and mathematics.

Staged in Italian, the play consists of five scenarios each on the paradoxes of the mathematical concept of infinity: 1. *Benvenuti all'Albergo Infinito* ('Welcome to the Hotel Infinity'), 2. *Vivere in eterno* ('Living forever'), 3. *Il paradosso della replicazione infinita* ('The infinite replication paradox'), 4. *L'infinito non è un grande* *numero* ('Infinity is not a big number'), and 5. *Viaggi nel tempo* ('Time travelling'). Of these, several touch on the deep mathematics of infinity, particularly the first that reproduces the hotel with countably infinite rooms of 20th-century mathematician Dave Hilbert, the third on infinite replication, and the fourth, which dramatizes the arguments between Cantor and Kronecker about the nature of infinity. The second envisages the possibility of living forever and reasons through the consequences of a similar scenario employing the technique of the *argumentum ad absurdum* already mentioned in paragraph 2.1 above; the fifth, less mathematical, scenario about time travel ends with a direct appeal to theatre critics, as seen in extract (8) below, which is indicative of the kind of abstraction the whole play aims to represent.

Infinities offers an interesting example of science on stage because of the contamination of the languages it experimented with, the language of science, on one hand, and dramatic language, on the other. Instead of dealing with the torments and dilemmas of a scientific character, or with scientific discoveries in the history of science, the play is meant to stage abstract scientific concepts and people's bewilderment in dealing with them, resulting in a new form of dramaturgy (Donghi 2013: 8, and see Barrow 2012 for the scientist's own recount of the staging experience).

The feeling of displacement it creates in the audience and in the actors alike is well captured by Kirsten Shepherd-Barr in her 2006 book *Science on Stage. From Dr Faustus to Copenhagen*, where she tries to reconstruct the peculiar theatrical experience of the audience, "Watching it we breathe the air of ideas and abstractions that are magically brought to life through the material possibilities of the stage" (Shepherd-Barr 2006: 150). She stresses how the play does not include plot and characterization as understood in traditional theatre terms, rather it "demonstrates the very concepts it deals with," thus constituting an innovative case in the genre of science plays (ibid.); see Fig. 3 for a suggestive picture from the play.

(8) *Infinities*

Se siete dei critici teatrali che viaggiano nel tempo e siete in grado di andare nel passato, potreste scrivere una recensione di questa commedia perché l'autore possa leggerla prima che venga scritta e rappresentata. Così gli consentireste di modificare le cose in modo da incontrare la vostra approvazione. Ma da dove sarebbe venuta la commedia? (*Infinities*, scenario 5)

Eng. back translation

If you are some theatre critics who travel in time and can go back to the past, you could write a review of this play so that the author can read it before it is even written and staged. In this way you would allow him to change things in a way as to meet your approval. But where would the play have come from?

Figure 3. A picture from scenario 1 of Infinities *(picture by Marcello Norberth/Piccolo Teatro di Milano – Teatro d'Europa)*

I will come back to *Infinities* to discuss the fourth vignette as an example of another type of argument widely used in the sciences, namely formal logic.

2.6 Digression as argument

Strictly connected with the previous technique seems to me to be the use of digressions as constitutive of argumentation in both Galileo and Feynman.

The four days of discussion in the *Two New Sciences* are intercalated with digressions, on friction, the vacuum and matter, each containing illustrations, thought and real experiments, which are introduced by Salviati and Sagredo to further clarify the main topic for the sake of Simplicio and the readership alike.

That digressions are constitutive of argumentation in the *Two New Sciences* is apparent when searching the text for lemmas such as *digressioni*, *digredire*, *divertire* pointing to digressions taking place throughout the development of the book including in the Corollaries at the end of the four days. There are 10 instances of *digressione/-i, digredir/-e* and 3 instances of *divertire, diverter, divertendo* with the same meaning in the first two days only.

The extract in (9) sees Sagredo purport digression as a heuristic, claiming that diversions from the main reasoning line may lead to novel ideas. This is not just a way of advocating freedom of thought typical of the new science, as pointed out by some commentators (e.g., Altieri Biagi 1983, Biagioli 1994), but also, and more important for an analysis of modes of scientific discourse, a method to explore and produce new knowledge:

(9) *Two New Sciences*

It.

SALV. In nuove specolazioni, e non molto al nostro intento necessarie, *converrà divertire*, se dovremo delle promosse difficoltà portar le soluzioni.

SAGR. Ma *se le digressioni* possono arrecarci la cognizione di *nuove verità, che pregiudica a noi,* non obbligati a un metodo serrato e conciso, ma che solo per proprio gusto facciamo i nostri congressi, *digredir ora* per non perder quelle notizie che forse, lasciata l'incontrata occasione, un'altra volta non ci si rappresenterebbe? *Anzi chi sa che bene spesso non si possano scoprir curiosità più belle delle primariamente cercate conclusioni?* (Giornata I)

Eng. tr.

SALV. To solve the problems which you raise *it will be necessary to make a digression* into subjects which have little bearing upon our present purpose.

SAGR. But *if, by digressions,* we can reach *new truth, what harm is there in making one now*, so that we may not lose this knowledge, remembering that such an opportunity, once omitted, may not return; remembering also that we are not tied down to a fixed and brief method but that we meet solely for our own entertainment? *Indeed, who knows but that we may thus frequently discover something more interesting and beautiful than the solution originally sought?* (Day I)

Feynman also conceptualizes the use of digressions as functional to his argument about mechanics and electromagnetism, and necessary in order to maintain the interest and enthusiasm of the better and more motivated students, as he states in the Preface to the *Lectures on Physics*. He takes digressions in a programmatic manner, asserting that he will apply concepts in directions which go beyond mainstream argumentation (Feynman 1995: xxiv), recalling Galileo's pedagogy of digressions.

2.7 Historicization and narrativization

A further strategy that is used not so much in Galileo, where the only other significant actor is Aristotle, but rather in Faraday, Feynman, Barrow and Miodownik, is what has been dubbed by Fuller 1998 among others (see also Hyland 2010) as 'historicization and narrativization' of science. This rhetorical strategy, which is linguistically expressed as a series of past tense verbs associated with the human agents of scientific discoveries, consists in narrating the story of science. It is employed by the scientist-writer for the sake of explanation and helps to narrow down the gap between writer and reader to the extent that the reader might gain a better understanding of natural phenomena.

As can be seen in extract (10), Feynman often uses this form of narration of what happened in the history of science. In explaining gravity he recounts the scientific discoveries by the great scientists from the past with whom he is entertaining a dialogue (Kepler, Copernicus, Galileo, Newton, Faraday, Maxwell, Einstein, etc.):

(10) *Six Easy Pieces*
In the years before 1920, the picture of space as a three-dimensional space, and of time as a separate thing, *was changed by Einstein*, first into a combination which we call space-time, and then still further into a curved space-time to represent gravitation. So the "stage" is changed into space-time, and gravitation is presumably a modification of space-time. *Then it was also found that* the rules for the motions of particles were incorrect. The mechanical rules of "inertia" and "forces" are wrong. *Newton's laws* are wrong in the world of atoms. Instead, *it was discovered that* things on a small scale behave nothing like things on a large scale. (*Six Easy Pieces*, p. 33)

Faraday quotes Hooke and his discoveries, "I have a drawing here sketched many years ago by Hooker, when he made his investigations" (Lecture I, pp. 12–13). Similarly, Barrow reconceptualizes the notion of zero to infinity by referring to Galileo and Cantor's reasoning on infinite numbers, and finally Miodownik explicitly mentions Galileo in his lecture on mechanics, when he says, "Galileo recognised this very early on and people have noticed this ever since" (*Size Matters*, 44' 31"). In this way, continuity with the history of science is established to facilitate understanding on the part of the audience.

2.8 Formal logic

Barrow's play allows me to tackle the use of formal logic in scientific discourse. The fourth scenario is developed by exploiting to the full the argumentative (and dramaturgical) potential of logical reasoning. Devoted to answering the questions "Can we count infinity?," "Are there infinities greater than other infinities?" it opens with the idea that infinity, most often denoted as ∞ (see Fig. 4), is an unbounded quantity that is greater than every real number and usually understood as "just a very big number," see the extract in (11) below that introduces common-sense thinking to which formal logic is then contrasted:

(11) *Infinities*
Questa idea che l'infinito sia solo un numero molto grande è quella che probabilmente ha in mente la maggior parte delle persone che vanno a teatro. Siamo tentati di pensare che per arrivare all'infinito basti contare senza mai fermarsi e che quindi sia approssimativamente il numero più grande che riusciamo ad immaginare, più qualche altra cosa. (*Infinities*, scenario n. 4)

[Eng. back tr. This idea that infinity is just a very big number is what most theatre goers probably have in mind. It is tempting to think that infinity is just a count that keeps on going, and so is approximately the biggest number we can think of, plus something more.]

However, the argument follows by presenting Galileo's paradox of the list of integers and their squared values, as in (12) below, and by dramatizing the formal abstraction of mathematical reasoning from Galileo to Cantor:

(12) *Infinities*

numero [number]	quadrato [square]
1	**1**
2	**4**
3	9
4	16
5	25
6	36
7	49
8	64
9	81
10	100 …e così via all'infinito…

[Eng. back tr. …and so on for ever…]

Following Galileo's logic, there is indeed a one to one correspondence between the two lists, thus they should be identical in size. However, the list on the left seems greater than the list on the right, because each number on the right-hand list is also contained in the left-hand list (see numbers in bold), so the left-hand list must be greater.

The scenario continues in the late 19th century with Cantor, who shows that not all infinities are countable (for example, the square root of 2, an irrational number, is not), therefore some infinities are greater than others. Non-countable infinities are a different type of infinity and a greater infinity, see "La gerarchia ascendente degli infiniti è senza fine. A partire da un insieme infinito, se ne può generare un altro più grande: basta considerare l'insieme che contiene tutte le "parti" dell'insieme di partenza. Questo viene chiamato il suo insieme potenza." [Eng. back tr. 'The ascending hierarchy of infinities is never-ending. From an infinite set we can create an infinitely larger set: by considering the set that contains all its subsets. This is called its power set'.].

Yet another example of formal logic is central to the scenario, concerning infinity creating chaos and ending on another paradox of infinity, namely that the sum of an infinite series can be either 0 or 1, depending on how we pair the members of the sum, see (13):

(13) *Infinities*
Consideriamo la serie infinita di +1 e -1 che si alternano e proviamo a calcolare la somma S di questa serie senza fine:

S = 1-1+1-1+1-1+….

Se associamo con parentesi a coppie i termini contenuti nella serie come appare qui sotto, la somma S della serie è ovviamente zero, perché ogni parentesi contiene una coppia di +1 e -1 la cui somma è zero:

S = (1-1) + (1-1) + (1-1) + (1-1) + …
S = 0 + 0 + 0 + 0 + …

quindi S = 0
Ma potremmo anche raggruppare i termini della serie in modo diverso, per esempio:

S = 1 + (-1+1) + (-1+1) + (-1+1) + …

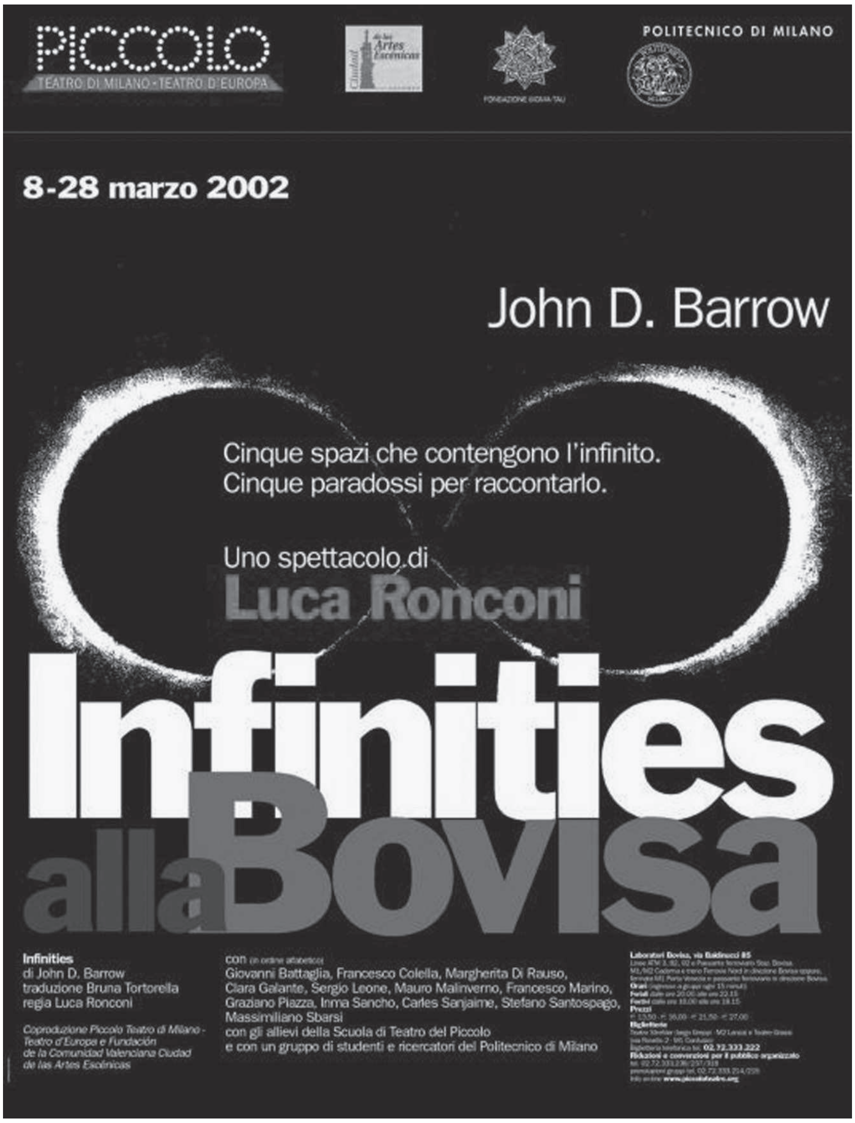
In questo caso S = 1 perché la somma all'interno di ogni parentesi è zero, quindi

S = 1 + 0 + 0 + 0 + 0 + …

A questo punto abbiamo dimostrato che S = 0 e S = 1, e quindi 0 = 1.
(*Infinities*, scenario 4)

[Eng. back tr. Let us consider the infinite series of alternating +1 and -1 and calculate the sum S of this never-ending series: S = 1-1+1-1+1-1+…. If we group the numbers of the series in pairs as shown below in brackets, the sum S of the series is obviously zero, because each bracket contains a +1 and -1 pair which sums to zero: S = (1-1) + (1-1) + (1-1) + (1-1) + … S = 0 + 0 + 0 + 0 + … and so S = 0. But, we could also group the terms in the series in a different way, for example: S = 1 + (-1+1) + (-1+1) + (-1+1) + … In this case S = 1 because each of the bracketed terms again sums to zero, so S = 1 + 0 + 0 + 0 + 0 + … We have now proved that S = 0 and S = 1, and so 0 = 1.]

Figure 4. A poster of the play Infinities *from the Piccolo Teatro's archive*



2.9 Series Reasoning

This particular type of reasoning seems to be as characteristic of Darwin's argument in the *Origin of Species and his biological and anthropological argument in the Descent of Man* as has been shown by Jeanne Fahnestock in her 1999 book on *Rhetorical Figures in Science*.

Fahnestock has noticed that Darwin uses series reasoning to replace differences in kind between different categories with differences in degree within one and the same category. This is functional to disproving the idea that there are as many independent acts of creation as are the various species, and to proving his evolutionary notion of species evolving from each other.

Talking about the scientist's "fixation on gradation through intermediaries" (Fahnestock 1999: 116), she has shown how series reasoning is present throughout the *Origin,* taking a figurative shape as *incrementum* and *gradatio*, the two figures of series formation which embody this type of argument. She defines *incrementum* as "the principle of ordering by increase or decrease in some quantifier or attribute," establishing a progression through ascending and descending series, while *gradatio* is "an easily recognised figure, constructed from a series of phrases or clauses, each of which, except the first, repeats the end of the previous item," thus concerning intermediates sharing some properties with previous and successive elements (Fahnestock 1999: 92–93). She also observes that the items being ordered must belong to the same genus or category, at least in the perception of the arguer. If not thus perceived by the audience, i.e., items in the *incrementum* are not already *within* the same category, then the figure can be used to establish membership, to argue for the very existence of the series.

This type of reasoning, which is crucial to the argument for a common origin, is also widely present in the naturalist's second treatise on human evolution, *The Descent of Man*. As can be seen in (14), Darwin employs the very term *gradation(s)* to hypothesise the evolutionary chain along a continuum. Series reasoning through *gradatio* is good for joining and blending what had been kept separate by the creationist argument (see the italicised words *steps*, *scale*, *gradation*/*graduating*, *degrees*, *interval*, etc.):

(14) *Descent of Man*

In the next chapter I shall make some few remarks on the probable *steps* and means by which the several mental and moral faculties of man have been *gradually evolved*. That such *evolution* is at least possible, ought not to be denied, for we daily see these faculties *developing* in every infant; and we may trace *a perfect gradation from the mind of an utter idiot, lower than that of an animal low in the scale, to the mind of a Newton.* (*Descent* [1871] 1981, p. 106)

> In a *series of forms graduating insensibly from some ape-like creature to man as he now exists*, it would be *impossible to fix on any definite point where the term 'man' ought to be used*. But this is a matter of very little importance. (*Descent* [1871] 1981: 235)

> (..) it is impossible to say *at what point in the ascending scale* animals become capable of abstraction, &c.; but who can say *at what age* this occurs in our young children? We see at least that such powers *are developed* in children *by imperceptible degrees*. (*Descent* [1871] 1981: 105)

> We must also admit that there is *a much wider interval* in mental power between one of the lowest fishes, as a lamprey or lancelet, and one of the higher apes, than between an ape and man; yet *this interval* is filled up by *numberless gradations*." (*Descent* [1871] 1981: 35)

2.10 Grammatical metaphor, or nominalization

The last feature I would like to briefly tackle is a particular rhetorical device that has been said to take place in the history of science discourse (see Altieri Biagi 1993 specifically on Italian scientific discourse), and identified by the British linguist M. A. K. Halliday as 'grammatical metaphor' (see Halliday 2004).

This is a metaphorical shift that occurs at the level of grammar, and consists in transforming verbs describing processes and events as they occur in the outer world and adjectives indicating qualities into nouns defining abstract entities. This kind of shift in the language is said to correspond to the birth of technical terms and the scientific jargon of modern experimental science (e.g., *motion*, *speed*, both derived from adjectives, and *fall* used as noun, as seen in the extract in (1) from the *Two New Sciences*), bringing about classification of phenomena into types and subtypes (e.g., *perpetual motion* in example (2) from *Six Easy Pieces*), generalization and theorization. The newly created entities which result from this process of nominalization and gradual abstraction offer the starting point for classification, measurement and some further argumentation to be developed. The verbs lexicalizing processes and events now turned into categories of natural phenomena become the topic for some further reasoning. In example (2) for instance, Feynman's argument rests on the distinction between two classes of machines, the reversible and non-reversible machines, a classification on which the whole reasoning is built and the conclusion about *perpetual motion* (an example of grammatical metaphor) is drawn.

That this metaphorical shift is pervasive in modern scientific discourse is evident not only in Galileo, where the transition from the verbal into a nominal representation of nature is still taking place linguistically (see in example (1) *mobile* 'body' used as noun rather than adjective, meaning 'that which can be moved,' or 'that which moves,' co-existing with *moto* 'motion' and *muoversi* 'move'), but also in the many examples from Faraday (e.g., *sun luminosity* in (3) above).

The scientific vocabulary of abstract entities, their qualities and subtypes and the reasoning based on these is obviously present in a mature science. However, in emerging new sciences, when a new theory is formulated and arguments provided to support it, like in Darwin's examples, the phrasing and the corresponding theorization make use of grammatical metaphor in a substantial way.

Darwin's *natural selection* and *evolution* (the latter of which, as is well-known, does not occur in the first edition of the *Origin*) are an example of such metaphorical shift that helps define an evolutionary theory later rhetorically amplified into *evolutionism* by Darwin's reception. *Natural selection*, or "the preservation of favourable variations and the rejection of injurious variations" occurs in nature as a process of selecting, preserving and favouring but, through nominalisation, it becomes a theory. In a similar way, all the following nouns from Darwin's treatise are grammatical metaphors: *variation, modification, deviation, preservation, adaptation, acclimatisation vs. extinction, destruction, extermination, degradation, competition*, etc.

Nominalization concludes this overview of the modes of scientific discourse and brings me to the last section of the present contribution.

3. Conclusions

Some recurring communicative and argumentative practices of scientists have emerged through the rhetorical analysis conducted on this sample of scientific texts. Continuity more than change has been observed in the modes of scientific discourse, at least as far as the cases considered allow to hypothesize. When considering continuity across disciplines, e.g., mechanics, biology and chemistry, and the ways of producing agreement these adopt, there seems to be convergence on shared modes of knowledge production and transfer.

Continuity is also observable across time and audiences as the types of scientific arguments resist diachronic change and are the same across different publics. Indeed, many of the types of argument that can be identified in Galileo's treatise appear in all other cases considered, somehow establishing an enduring tradition. However, it should be stressed that all the texts analyzed were addressed to a wide audience, and meant to accommodate mixed groups of addressees, whether 17th- and 19th-century intelligentsias (cf. Galileo, Darwin), present-day educated theatre goers (Barrow), the general public and children (Faraday, Miodownik), or 20th-century university students (as in Feynman's lectures). In a way, although perhaps to different extents, proselytism is at work in all the texts analyzed.

The instances considered share the same emphasis on experimenting as constitutive of science and on showing and giving demonstrations as facilitating understanding of specialized contents on the part of the viewing audience, whether student-novice, lay-public or peer scientists. The dialogicity typical of the spoken medium is also found to be characteristic. This reinforces the idea that science is interactive and that scientific argumentation requires interpersonal negotiations and engagement as much as convincing ideas, so it is 'rhetorical action' (Ceccarelli 2001; see also Selzer 1993). Imagination, visualization and embodiment as much as appeal to emotions appear to be indispensable qualities of successful apprenticeship into science.

Also, science builds on its past when in order to explain novel theories scientists embark on a narrative of the history of science. Specialized knowledge becomes easier to grasp when its history is recounted.

To conclude, with this approach I hope to have shown that rhetoric of science is a fruitful investigative tool that helps to develop understanding of scientific cultures when dealing with 17th century as well as contemporary scientific discourse.

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