



Feature Articles

Dante Alighieri Science Communicator

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Abstract. This paper deals with the issue of communication and dissemination of scientific knowledge outside the circle of specialists. In particular, in the occasion of the 700th anniversary of the death of Dante Alighieri, we will focus on the program for the popularization of knowledge outlined by Dante in the *Convivio* and *De Vulgari Eloquentia*, as well as several examples taken from his *Divine Comedy* concerning mathematical and natural sciences. Some solutions for communicating science proposed by Dante, such as the explanations of principles and scientific methods within a narrative framework (now often called the storytelling method), in addition to dialogues between characters, anticipate methods for science communication used by several authors after him. Examples are provided to show the depth of Dante's knowledge concerning the basic concepts and methods of mathematics, physics and natural sciences (such as chemistry, meteorology, astronomy etc.). In addition, the examples demonstrate how effectively Dante used analogies and metaphors taken from sciences within his poetry.

Keywords: Science popularization, Dante Alighieri, Divine Comedy, Medieval philosophy

1. INTRODUCTION

In Europe, during the 12th Century, there was a considerable spread of knowledge due to translations of texts from Greek and Arabic into Latin, especially in Toledo (south of Spain) and Palermo (at the court of Frederick II of Sicily), two cities where a mixture of Arabian, Greek and Latin cultures thrived side by side for many years, as well as in several other places. Authors whose works were translated into Latin included Aristotle, Ptolemy, Euclid, Archimedes, Alhazen, and Al-Khwarizmi, together with Chinese and Indian texts imported in Europe through Arabic versions. Such an abundance of Latin texts triggered the creation of a network of universities that used Latin as a *lingua franca* and favored an intensive exchange of international scholars and texts. The universities of Oxford, Coimbra, Paris, Montpellier, Bologna, and Salerno were founded in the 12th century, and those of Cambridge, Salamanca, Toulouse, Orleans, Naples and Padua in the 13th century (see e.g. Greco, 2014). In these universities the arts of the *Trivium* (grammar, rhetoric, dialectic) and those of *Quadrivium* (arithmetic, geometry, music, astronomy) became common subjects for all students.

At the same time, most particularly in the 13th century, *Abacus schools*, used by the emerging classes of merchants, craftsmen, artists, bankers and their sons, were created in many Italian cities. In these schools, popular (vulgar) Italian language and writing, as well as basic mathematics, accounting, mechanics and other subjects, were taught mainly through examples for practical purposes. Dante probably attended this kind of school when he was a child, as he was the son of a merchant, and as an adult he probably attended some lessons at universities as well, in Bologna and Padua, perhaps even in Paris. Therefore, he was probably familiar with both kinds of knowledge – the more theoretical kind taught in Latin at universities and the more practical one taught in the vulgar language at Abacus schools.

Moreover, Dante became used to Italian vulgar poetry, which originated at the court of Frederick II in Sicily and was adopted by many poets and scholars who shared this passion with Dante.

In the 13th century new knowledge and new texts (written in Latin) became more generally widespread in Europe, from the *Liber Abaci* by Leonardo Pisano (Fibonacci) to *Optics and Mathematics* by Robert Grosseteste, *Treatise on Astronomy and Astrology* by John Sacrobosco and *Summulae Logicales* by Pedro Hispano, just to quote a few. All these texts were addressed to an intellectual élite. Indeed, many scholars held an elitist idea of knowledge, especially regarding philosophy and science (often known as natural philosophy). This was, for example, the opinion of Islamic scholar Averroes (Cordova 1126 - Marrakech 1198), a famous philosopher, doctor, judge, and author of commentaries on Aristotle, who stated that teaching humble people was a wasted effort, and even dangerous because it could lead to misunderstandings, and could be a source of discouragement and humiliation for those who did not have the tools to understand. By contrast, Dante Alighieri (Firenze 1265 - Ravenna 1321) held a very different opinion. He firmly expressed a democratic idea of knowledge which should be provided to everybody, although at different levels and through different tools. He discussed these ideas in two unfinished books: *Convivio* (written in the vernacular) and *De Vulgari Eloquentia* (in Latin). In these two treatises Dante outlined a detailed program for the dissemination of knowledge. Indeed, *convivio* means banquet, a table that offers the participants the difficult “food” of knowledge, accompanied by the bread that will facilitate its assimilation. In fact, this work is a kind of encyclopedia in which Dante explains the great philosophical themes of his time in a language which is comprehensible even to non-specialists, themes ranging from linguistics to science, cosmology and politics. In

the preface Dante explains why a book like *Convivio* is needed and why it is written in the vernacular instead of Latin. Moreover, he clearly states that “all men naturally desire to know” and “science is the ultimate perfection of our soul”.

In *De Vulgari Eloquentia* (On Vulgar Eloquence), written slightly earlier, Dante examines the problem of the most suitable language to spread knowledge in a universal, clear and effective way. After a comparison between Latin and the vernacular, Dante considers the “excellent vernacular speech, common to all Italians, which can be learned without other rules by imitating the nurse”; in other words, the native language. It was written in Latin as it was addressed primarily to the scholars of the time, in order to show them the beauty and usefulness of Italian popular language. Its objective was the search for a natural language that could be understood by all Italians, obtained through a comparative study of different regional dialects and of the way these evolved, in order to find the words and expressions that could be appreciated by people of any Italian region. Finally, in this book Dante analyzes the more suitable metric structures for the poetic form of *canto* (or song), which is a literary genre developed in the Sicilian School of poetry. This poetic form, thanks to its metre and use of rhyme, allowed Dante to produce a poem which was suitable for being read out loud and easily memorized so that it could be learned and repeated even by illiterate people. That is exactly what Dante will do in the *Commedia*, called *Divina* by Giovanni Boccaccio.

It is worth noting that Dante also identifies another difficulty that was emerging in the 13th century. This concerned the specialization of languages within the various professions – thus anticipating a problem that would become a major obstacle to the spread of knowledge today, as maintained by C.P. Snow in his famous essay “The Two Cultures” of 1959. In order to describe this problem, in *De Vulgari Eloquentia* Dante proposes his own personal reworking of the well-known biblical legend of the Tower of Babel, where the external influence of God who confuses languages, is replaced by an endogenous, or evolutionary, explanation of the differentiation of languages. After reporting the classical version:

Almost the whole of the human race had collaborated in this work of evil. Some gave orders, some drew up designs; some built walls, some measured them with plumb-lines, some smeared mortar on them with trowels; some were intent on breaking stones, some on carrying them by sea, some by land; and other groups still were engaged in other activities - until they were all struck by a great blow from heaven. Previously all of them had spoken one and the same language while carrying out their

tasks; but now they were forced to leave off their labours, never to return to the same occupation, because they had been split up into groups speaking different languages.

Dante provides his own explanation:

Only among those who were engaged in a particular activity did their language remain unchanged; so, for instance, there was one for all the architects, one for all the carriers of stones, one for all the stone-breakers, and so on for all the different operations. As many as were the types of work involved in the enterprise, so many were the languages by which the human race was fragmented; and the more skill required for the type of work, the more rudimentary and barbaric the language they now spoke.

Today we would say that doctors speak using their own specific language as do physicists, mathematicians, chemists, philosophers, etc., and as a result they no longer understand each other. Hence, someone is needed (the scientific journalist, the populizer, etc.) who is responsible for finding a way to communicate knowledge to everyone by using a common suitable language

In the *Divina Commedia*, many passages can be noticed in which the author shows that he is perfectly at ease not only with astronomy (which is obvious given the structure of the entire work) but also with arithmetic, geometry, logic, physics, and natural sciences in general, to the extent that he uses the stories and the dialogues included in the *Comedy* to communicate scientific concepts and theories, sometimes even at a rather sophisticated level for his times. In the following we shall examine and comment on some of these passages.

2. PHYSICS AND MATHEMATICS IN PARADISE

Let us start from *Paradiso*, Canto 2 (94-106), where Dante clearly illustrates the method of experimental science three hundred years before Galileo. He uses the words of Beatrice, his beloved guide throughout the trip in Paradise, to state how strong his faith in laboratory experiments is. Dante and Beatrice are ascending towards the first heaven of the Moon and the poet asks her what is the origin of the moon spots. Beatrice invites him to express his opinion and Dante attributes the phenomenon to the greater or lesser density of the celestial body (see e.g. Greco, 2009). Beatrice then announces an explanation that, based on an experiment, will refute Dante's theory:

Da questa istanza può deliberarti
esperienza, se già mai la provi,
ch'esser suol fonte ai rivi di vostr'arti. 94

[From this objection an experiment
can free you, if you ever try it,
for from experience derives the source of all your arts.]

That is to say: an experiment can reveal the fallacy of your explanation, as experiments are the starting points of all your knowledge. The statement is peremptory: all your knowledge (down on Earth) comes from experiments. Note that in this case experience is used to disprove definitively, and not to prove something – a form of what six centuries later Karl Popper will propose as the “Falsification Principle”, a way of defining science from non-science, which is at the basis of the scientific method. However, Beatrice does not limit herself to such a statement, as she immediately moves on to the description of a real laboratory experiment:

Tre specchi prenderai; e i due rimovi
da te d'un modo, e l'altro, più rimosso,
tr'ambo li primi li occhi tuoi ritrovi 97

Rivolto ad essi, fa che dopo il dosso
ti stea un lume che i tre specchi accenda
e torni a te da tutti ripercosso. 100

Ben che nel quanto tanto non si stenda
la vista più lontana, li vedrai
come convien ch'igualmente risplenda 103

[Take three mirrors, and place two of them at the same distance from you, and let your eyes find the third more distant and between the first two.

Facing toward them, have a light from behind you shine on the three mirrors and return to you reflected from all three.

Even though the more distant image is not as extended in size, you will see that it is equally bright there]

We will not dwell on the details of the experiment but rather highlight the point that Dante, through the words of Beatrice, is suggesting that an experiment be carried out on Earth in order to understand an astronomical phenomenon, thus affirming that the laws of terrestrial physics coincide with those of celestial physics. Galileo will have to work hard on such an argument in order to convince Aristotelians in the 17th century. And even the statement about experience as the main source of knowledge sounds quite advanced for his time, as it anticipates what will become commonly accepted only after the scientific revolution of the 17th century.

In this regard, it is also important to mention Dante's opinion about alchemists, as he imagines them

to be expelled without any appeal, in the Tenth Bolgia of Hell, where they join the company of falsifiers and swindlers. In fact, in Canto 29 of *Inferno*, Dante meets some alchemists who are tormented as they are not able to see anything on account of the darkness. Two of them, Grifolino of Arezzo and Capocchio of Siena, present themselves to Dante.

«Io fui d'Arezzo, e Alberto da Siena», 109
rispuose l'un, «mi fé mettere al foco;
ma quel per ch'io mori qui non mi mena.

Vero è ch'i' dissi lui, parlando a gioco: 112
“I' mi saprei levar per l'aere a volo”;
e quei, ch'avea vaghezza e senno poco,

volle ch'i' li mostrassi l'arte; e solo 115
perch'io nol feci Dedalo, mi fece
ardere a tal che l'avea per figliuolo.

Ma nell'ultima bolgia de le diece 118
me per l'alchimia che nel mondo usai
dannò Minòs, a cui fallar non lece».

[«I'm from Arezzo, and Albert of Siena»
one of them replied, «had me burned,
but I'm not here for what I died for there.

It's true I told him, jokingly, of course:
“I know the trick of flying through the air”, ‘
and he, eager to learn and not too bright,

asked me to demonstrate my art; and only
just because I didn't make him Daedalus, he had me
burned by one whose child he was.

But here, to the last bolgia of the ten,
for the alchemy I practiced in the world
I was condemned by Minos, who cannot err».]

In other words, even if Grifolino died because Alberto of Siena ordered to burn him as a consequence of his false claim about his ability to fly, after his death Minos, the judge and guardian of Hell, condemned him to the Tenth Bolgia just because he was an alchemist. It is important to point out that in the time of Dante alchemy was considered a method to investigate and imitate Nature, as stated by the other alchemist speaking to Dante:

si vedrai ch'io son l'ombra di Capocchio, 136
che falsai li metalli con l'alchimia;
e te dee ricordar, se ben t'adocchio,

com'io fui di natura buona scimia». 139

[then you will see that I am the shade of Capocchio, who
falsified metals with alchemy;
and you must remember, if I eye you well,

how good an ape I was of nature.”]

In other words, Capocchio believes that Dante should remember him as a good imitator of nature. Despite this, the poet places him in Hell, among those who took advantage of their knowledge to get rich by deceiving others.

Now we go back to Paradise, but we move onto mathematics, as there are really many references to this discipline in the Comedy (for a more complete treatment of this topic, see e.g. D'Amore, 2001, or Bischi, 2015). We start from *Paradiso*, Canto 33, where the Poet wonders about the difficulty to understand the mystery of the Incarnation, that is, the concept of how Christ can be both human and divine at the same time. This is not impossible for God, but difficult to demonstrate by a limited human mind. How could Dante find an example to explain such difficulty? He refers to the famous (unsolved) problem of Greek geometry known as the problem of squaring the circle, i.e. finding the sides of a rectangle whose area is equal to that of a circle of a given radius:

Qual è 'l geomètra che tutto s'affige 133
per misurar lo cerchio, e non ritrova,
pensando, quel principio ond'elli indige:

tal era io a quella vista nova; 136
veder voleva come si convenne
l'imgo al cerchio e come vi s'indova.

[Like the geometer who is all intent
to square the circle and cannot find,
for all his thought, the principle he needs:

such was I at that miraculous sight;
I wished to see, as was fitting
the image to the circle, and how it enters therein]

This mathematical problem reminds Dante of the mystery of the Incarnation, that is, two things of a different nature, one penetrated by the other. This problem was impossible to be solved in Euclid's geometry because, in ancient Greece, geometry problems had to be solved by geometric constructions involving only the use of an ungraduated ruler and a compass. Such an approach constitutes a form of mental gymnastics, or a test of skills. Indeed, Dante knew very well how to calculate the area of a circle, and in fact he uses the approximation $22/7 = 3.1428\dots$ (often used instead of π

= 3.1415... in the Abacus books of the Middle Ages) to measure a circular bolgia. Thus, the poet's suggestion is really remarkable: the squaring of the circle (as well as the Incarnation of God) is not impossible to achieve in principle, but it becomes impossible to understand it if resorts only to the use of limited tools, such as a ruler and compass in geometry or the human mind in theology. Of course, this example is not easily understood by any reader of the Comedy, as it requires a deep knowledge of Greek geometry.

Similar arguments apply to the following passage, taken from *Paradiso*, Canto 28, where a reader is assumed to know the legend behind the invention of the game of chess often reported in Abacus books as an example of the exponential growth of compound interests. In this passage Dante uses the metaphor of sparks issuing from a fire to describe the number of angels revolving around God. But how many are them? The poet could write "so many as the stars in the sky", or "so many as the grains of sand in the sea". By contrast, Dante prefers to use an arithmetic argument:

L'incendio suo seguiva ogni scintilla; 91
ed eran tante, che 'l numero loro
più che 'l doppiar delli scacchi s'inmilla

[Each spark followed its fire,
and they were so many that their number enthouasands
itself beyond the doubling of the chessboard.]

Dante refers to the famous legend of Sissa Nassir, a court magician, and inventor of the game of chess, to whom the Persian king promised the reward he desired for his invention. The witty inventor then made an apparently modest request: taking the chessboard, the usual square formed by 8 by 8 squares, he asked for a grain of wheat on the first square; twice as much, that is 2 grains, on the second, twice as much again, that is 4, on the third; and then 8, 16, 32 ... up to the last 64th square, where 2⁶³ grains are required. But as soon as the king realized that the total quantity of grain required to meet the demand was so huge, being of the order of ten billion of billion of grains, instead of rewarding Sissa Nassir he had him killed. This legend was reported as an example in many abacus books, as this "game of doubling" (or exponential increase) was used as a template for calculating compound interest, and used by banks in Dante's time, when commerce and entrepreneurial activities started to ask for loans, often at rates that today would undoubtedly be defined as usury.

With these two examples, we have seen how Dante was familiar with both learned mathematics (such as Euclid's *Elements*) taught in Latin at universities, and

practical mathematics, the kind taught in the vernacular in Abacus schools.

Keeping to the subject of mathematics (and of kings), let us turn to the story of Solomon reported in *Paradiso*, Canto 13 (88-103). Solomon was king of Israel from 970 to 931 BC, and he was famous for his wisdom and knowledge. He became king at a very young age, and the Bible says that the Lord appeared to him in a dream and told him: "Ask me what I must grant you" and Solomon replied: "Lord my God, you made your servant reign in place of David my father. But I am a boy; I do not know how to rule. Give your servant a mild heart, that he may know how to do justice to people, and how to distinguish right from wrong". It pleased the Lord that Solomon had asked for wisdom in ruling, and he said to him: "Why did you ask for this thing, and did not ask for yourself a long life, nor riches, nor the death of your enemies? Behold, I grant you a wise and intelligent heart, but I also grant you what you have not asked for, that is, riches and glory such as no king ever had".

Dante reports the essence of this legend, but in doing so he replaces the requests Solomon did not make with his own wishes:

Non ho parlato sì che tu non posse 94
ben veder ch' el fu re che chiese senno
acciò che re sufficiente fosse,

non per sapere il numero in che enno 97
li motor di qua sù, o se necesse
con contingente mai necesse fenno,

non si est dare primum motum esse, 100
o se del mezzo cerchio far si puote
triangol sì ch'un retto non avesse.

[I have not spoken in such a way that you cannot see clearly that he was a king asking for the wisdom to be a worthy king,

not in order to know the number of the
Movers up here, or if necesse
with contingent ever made necesse ,

not si est dare primum motum esse,
or whether in a semicircle one can make
a triangle that lacks a right angle.]

In other words, Dante would have asked God information about the number of angels (appointed to move planets and stars), or whether in a logical proposition a necessary premise combined with a contingent one will give a necessary consequence (a problem which is not trivial, and had already been tackled and negative-

ly resolved by Aristotle), or whether there can be a first motion, i.e. which is not derived from another motion, or, finally, if a triangle that does not have a right angle can be inscribed in a semicircle.

Dante proposes these questions as examples of something false, because they contradict modes of logical necessity. If there is a motion, then necessarily there is a cause, i.e. another motion that generated it (inertia principle will be proved later, by Galileo). If a triangle is inscribed in a semicircle, then necessarily that triangle is rectangular, a direct consequence that the sum of all three angles is equivalent to a flat angle, which follows from the axiom of parallels (the so called 5th postulate of Euclid geometry). Now, while the statement of physical nature is linked to the question of the existence of God, who was able to create everything from nothing, therefore also to originate movements from nothing, the last statement concerns a rather unexpected example from geometry. Moreover, it expresses a doubt about the validity of a basic axiom of Euclidean geometry, in particular the fifth postulate. This may raise the question as to whether alternative geometries can exist, namely the non-Euclidean geometries that will be introduced in the 19th century. Probably we are going too far with our imaginations and we are also pushing Dante's imagination too far.

A similar argument applies to the following passage, found in *Paradiso*, Canto 15 (55-57) where Dante has just met his ancestor Cacciaguida and wants to tell him that he is so wise and forward-thinking that he seems to understand his words before he speaks, as if Cacciaguida were able to read his thoughts. The description of this situation, expressed by Cacciaguida's words while talking to Dante, may suggest to a modern mathematical reader a method for the construction of the whole set of natural numbers based on the principle of induction:

Tu credi che a me tuo pensier mei 55
da quel ch'è primo così come raia
da l' un , se si conosce, il cinque e 'l sei ,

[You believe that your thought flows to me
From him who is First, just as from one, if known, ray
forth both five and six,]

This is a very famous phrase that Cacciaguida addresses to Dante: you believe that all your thoughts come to me from God (from him who is first) just as all numbers can be derived from number one (for example six comes from five by adding one). In modern notations we would say "given number 1, then from n we get $n+1$ by induction. However, this general notation that uses variables instead of numbers, was not yet used in Dante's

time. For this we have to wait for François Viète in the 16th century. Dante just takes two consecutive numbers at random, such as 5 and 6, to say that this rule applies to all numbers. This mathematical metaphor used by Dante is really remarkable as it can be seen as a metaphor of Creation as well, because one can generate an infinite number of objects by just starting from unity.

3. METEOROLOGY, PROBABILITY AND CHEMISTRY IN PURGATORY

Let us descend now into Purgatory, where Dante meets Bonconte da Montefeltro in Canto 5 (88-129). Bonconte was the military leader of the Ghibellines of Arezzo against the Florentine Guelphs in the battle of Campaldino in 1289. Bonconte suffered defeat, he died during the battle and his body was never found. The whole story is interesting, showing a struggle between the powers of good and evil for his soul, and since he had uttered the name of Mary with his dying breath and shed a tiny tear, the heavenly faction prevailed and brought his soul into Purgatory. However, a demon took possession of his body and dispersed it into a river flood after a big storm. The description that Bonconte gives to Dante about the weather situation leading up to the storm is a page of intensive scientific revelation.

What is remarkable is the way Bonconte introduces himself (*Purgatorio* Canto 5, 88) «Io fui di Montefeltro, io son Bonconte» («I was from Montefeltro, I am Bonconte») – where the usage of both past and present tense means that when alive on Earth, he belonged to the noble family of Montefeltro whereas now in the life beyond, he is just himself. This shows the way in which Dante chooses any detail with a precise meaning.

Let us now turn to Bonconte's description of the separation of his soul from his dead body and of the storm that caused the loss of his body in the river.

Io dirò vero, e tu 'l ridi tra ' vivi: 103
l'angel di Dio mi prese, e quel d'inferno
gridava: "O tu del ciel, perché mi privi?"

Tu te ne porti di costui l'eterno 106
per una lagrimetta che 'l mi toglie;
ma io farò de l'altro altro governo!"

Ben sai come ne l'aere si raccoglie 109
quell' umido vapor che in acqua riede,
tosto che sale dove 'l freddo il coglie.

Giunse quel mal voler che pur mal chiede 112
con lo 'ntelletto, e mosse il fummo e 'l vento
per la virtù che sua natura diede.

Indi la valle, come 'l dì fu spento,
da Pratomagno al gran giogo coperse
di nebbia; e 'l ciel di sopra fece intento,

115

si che 'l pregno aere in acqua si converse;
la pioggia cadde, e a' fossati venne
di lei ciò che la terra non sofferse;

118

e come ai rivi grandi si convenne,
ver' lo fiume real tanto veloce
si ruinò, che nulla la ritenne.

121

Lo corpo mio gelato in su la foce
trovò l'Archian rubesto; e quel sospinse
ne l'Arno, e sciolse al mio petto la croce

124

[Now hear the truth. Tell it to living men:
God's angel took me up, and Hell's fiend cried:
"O you from Heaven, why steal what is mine?

You may be getting his immortal soul
won it for a measly tear, at that,
but for his body I have other plans! '

You know how vapor gathers in the air,
then turns to water when it has returned
to where the cold condenses it as rain.

To that ill will, intent on evilness,
he joined intelligence and, by that power
within his nature, stirred up mist and wind.

Then the valley, by the end of day,
from Pratomagno to the mountain chain,
was fogbound; and dense clouds charged the sky:

so that the saturated air turned into water;
rain poured down, and what the sodden ground
rejected filled and overflowed the deepest;

gullies, whose spilling waters came to join
and form great torrents rushing violently,
relentlessly, to reach the royal stream.

Close to its mouth the raging Archiano
discovered my cold body-sweeping it
into the Arno, loosening the cross]

Quite remarkable is the description (109-111) of the water cycle, due to water evaporation and then condensation into liquid water again when the steam, as it rises, encounters colder air layers. This provides a clear-cut explanation of a meteorological phenomenon that was not so clear to people living in the 13th century (see e.g. Cornish, 2004). Moreover, the description of the whole process of storm occurrence and water flow towards rivers is very rigorous and worthy of a scientific essay.

An often-quoted passage of Purgatory, dealing with mathematical ideas given by Dante in the *Comedy*, is the description of a game of dice in Canto 6 (1-3), where an anticipation of some flavor of the concept of probability can be noticed:

Quando si parte il gioco della zara,
colui che perde si riman dolente,
repetendo le volte, e tristo impara

1

[When the zara game starts,
the loser remains sorrowful,
repeating his throws, and sadly he learns]

In the *zara game* (Arabic word 'zahar' means 'dice'), which was very popular in Dante's time, each player bets a certain amount of money before three dice are thrown and each of the players, in the short time between throwing the dice and then stopping them, says a number – whoever guesses the result wins the prize. If no one guesses correctly, the amount of money to be won in subsequent games increases. Of course, probability theory has a role in the analysis of this game; however this theory did not exist at Dante's time, as we have to wait for Cardano (1501-1576), Galilei (1564-1642), Fermat (1601-1665) and Pascal (1623-1662) for these concepts to be introduced in mathematics. However, the combination of the two words "*repetendo ...impara*" (*repeating ... learns*) may reveal an intuitive, veiled awareness of the existence of probability laws. If a player learns, it means that there is something to be understood, hence Dante may be aware that not all outcomes are equally probable, in the sense that some outcomes are more frequent than others. Moreover, "*repetendo*" makes one think of a "frequentist" definition of probability, given by the number of occurrences of the event divided by the number of trials, as the number of trials tends to infinity. Naturally this is a rather modern interpretation that cannot be attributed to Dante. However, the sentence is surely intriguing, as it was in the question about triangles without right angles in a semicircle in the Solomon story.

Finally, in *Purgatorio*, Canto 7 (73-75) we can find evidence of Dante's knowledge of chemical elements. Indeed, after the enactment of the Orders of Justice in 1293, Dante joined the order of physicians and apothecaries (ancestors of our pharmacists) in order to participate in political life. In addition to medicines however, apothecaries also produced materials for painters, such as white lead, which is lead carbonate, and Dante in his *Vita Nova* tells of having painted. He painted on wood and therefore had to know the methods of preparation of the wooden boards before painting them. So, we may

hypothesize that his joining the order of doctors and apothecaries was due to this practice, at least as a novice. A description of these materials is given in the following passage:

Oro e argento fine, cocco e biacca, 73
indaco, legno lucido e sereno,
fresco smeraldo in l'ora che si fiacca,

da l'erba e da li fior, dentr'a quel seno 76
posti, ciascun saria di color vinto,
come dal suo maggiore è vinto il meno.

Non avea pur natura ivi dipinto, 79
ma di soavità di mille odori
vi facea uno incognito e indistinto.

[Think of fine silver, gold, cochineal, white lead,
Indian wood, glowing and deeply clear,
fresh emerald the instant it is split,

the brilliant colors of the grass and flowers
within that dale would outshine all of these,
as nature naturally surpasses art.

But nature had not only painted there:
the sweetness of a thousand odors fused
in one unknown, unrecognizable.]

In the second Terrace of the Ante-Purgatory, the poet Sordello shows Dante and Virgilio the flowery valley where the negligent princes are located: in their lives they were guilty of neglecting their spiritual and earthly duties. Dante sees that nature here is luxuriant and beautiful as the grass and flowers have such vivid colors as to surely win the most precious and refined hues used by painters, such as gold, silver, emerald. And the spectacle is not only visual, as the flowers give off a scent that mixes a thousand sweet smells. This can be seen as proof of Dante's knowledge about chemicals (which give rise to colors and smells). In other words, we believe that Dante's involvement in the world of the apothecaries, where chemistry took its first steps, gave him more knowledge and understanding than the pseudoscientific alchemy practitioners, as mentioned in Section 2.

4. LOGIC AND GRAVITATION IN HELL

Let us now turn to *Inferno*, Canto 27 (112-123), where among the fraudulent advisers we find Guido da Montefeltro, father of Bonconte, duke of Urbino from 1293. He was also a Ghibelline military leader, and won many important battles often against the Papal army.

Then he became a friar and entered the Franciscan monastic order in Assisi in 1296, where he died in 1298.

While he was in the monastery, Pope Boniface VIII asked him for advice in order to win a difficult battle. Guido argued that he could give him a suggestion but it would involve a lie, and Guido knew that as a friar he could not commit such a sin. But Boniface told him, "don't worry, I can absolve you before you commit it". Hence, the Pope absolved him in advance and Guido was allowed to give his fraudulent advice. When Guido died, Francis of Assisi personally picked him up to take him directly to Heaven (this was a privilege of the Franciscan friars). However, something unexpected happened due to a logical reasoning, a typical argument of formal logic which nowadays can be expressed by the symbolism of logical operators or set theory. Here is the beginning of the story:

Francesco venne poi, com'io fu' morto, 112
per me; ma un d' i neri cherubini
li disse: "Non portar: non mi far torto.

[Francis came later, when I had died,
for me; but one of the black cherubins
told him: 'Do not take him, do not wrong me.]

Here Guido is telling his story, starting from St. Francis who went purposely to take him ("for me"), but a black cherub, that is, an angel of Hell, ordered St Francis not to take him. It may seem really implausible that an anonymous black cherub gives orders to St. Francis, but as Dante will reveal to us, he is not just any cherub, because he is a logician as well. Notice that here we have a struggle between the powers of good and evil similar to the struggle we have seen for the soul of Bonconte da Montefeltro, the son of Guido. However, here the outcome will be different:

Venir se de dee giù tra 'miei meschini 115
perché diede 'l consiglio frodolente
dal quale in qua stato li son a' crini;

ch' assolver non si può chi non si pente, 118
né pentere e volere insieme puossi
per la contraddizion che nol consente".

Oh me dolente! come mi riscossi 121
quando mi prese dicendomi: "Forse
tu non pensavi ch' io loico fossi"!

[He must come down among my slaves,
Because he gave the fraudulent counsel,
since when, until now, I have been at his heels;

for he cannot be absolved who does not repent,

nor can one repent and will together,
because of the contradiction, which does not permit it.’

Oh wretched me! how I trembled
when he seized me, telling me: “Perhaps
you did not think I was a logician!”]

The black cherub asserts that Guido must instead go down with him to Hell because he gave fraudulent advice, after which the cherub was always at his heels – a powerful image implying that the devil follows the sinner from the moment a sinful action is committed until he manages to take him to Hell. But Dante’s masterpiece comes with logical proof to demonstrate that putting Guido in Paradise is a contradiction with respect to the laws (i.e. the axioms) of the Church. In fact, one cannot absolve someone who does not repent, nor is it possible to repent of sin and at the same time want to commit it, because this would lead to a contradiction. In short, faced with the evidence of a logical demonstration there is no getting round it. Not even St Francis, founder of the order, can counteract.

A question naturally raises concerning the level of Dante’s knowledge about logics. A possible answer comes from the following statement in *Paradiso*, Canto 12 (134-135):

... e Pietro Ispano, 134
lo qual giù luce in dodici libelli

[... and Peter of Spain,
who shines down there in twelve volumes]

where Dante says that Peter of Spain (or Petrus Hispanus) was famous on Earth (“shines down there”) being the author of the twelve chapters that make up the *Summule logicales*, a compendium of formal logic that was the reference manual on Aristotelian logic in use in European universities for more than 300 years. Dante does not mention the fact that Petrus was also a Pope under the name of John XXI. In short, according to Dante, Peter of Spain was famous for writing texts on logic, not for being a Pope. Therefore, we can deduce that Dante, having read and appreciated such a text, was able to understand and handle subtle questions of logic such as the one raised by the black cherub. And, of course, he used the *Commedia* to communicate such knowledge to people who did not have access to universities.

As a final example (among many others) of science vulgarization through the pages of the *Divina Commedia* we propose a passage from the last Canto of *Inferno*, Canto 34 (100-111), where Dante uses a remarkable narrative trick to describe the force of gravity as a centrip-

etal force field directed towards the center of the Earth. In order to explain this, Dante tries to describe what should happen while passing through the center of the Earth, where in the *Commedia* Lucifer is located (see Figure 1, where the spatial structure of the Dante’s universe is illustrated).

The last portion of Hell, before it is closed by the horrible hairy body of Lucifer located at the center of the Earth, is formed by the last area of Cocito, the Giudecca, where the traitors of the benefactors are severely punished by being imprisoned in ice. Dante and Virgilio move towards Lucifer and the Latin poet invites the disciple to embrace him around his neck while looking for the right moment to step over the Lucifer’s body in order to continue the trip beyond the center of the Earth to the other hemisphere. When the monster’s wings are open enough, Virgil clings to Lucifer’s hairy ribs and descends along the demon’s flanks, then, out of breath, he turns and clings to the hairy legs, beginning to climb upwards. Dante, attached to his neck, does not realize what really happened, and he wrongly believes that they are returning back to the Giudecca. In fact, before twisting around Lucifer, he feels the force of gravity pushing him, while now he feels it opposing his direction of motion. Because of this he thought he had inverted the direction of his movements, like when you go downhill and then you retrace your steps when going uphill. This is the reason for the following questions, which reveal how Dante remains confused due to the centripetal direction of gravity force:

«Prima ch’io de l’abisso mi divella, 100
maestro mio», diss’io quando fui dritto,
«a trarmi d’erro un poco mi favella:

ov’è la ghiaccia? e questi com’è fitto 103
sì sottosopra? e come, in sì poc’ora,
da sera a mane ha fatto il sol tragitto?».

Ed elli a me: «Tu imagini ancora 106
d’esser di là dal centro, ov’ io mi presi
al pel del vermo reo che ‘l mondo fóra.

Di là fosti cotanto quant’ io scesi; 109
quand’ io mi volsi, tu passasti ‘l punto
al qual si traggon d’ogne parte i pesi.

[«Before I am uprooted from the abyss,
my master», said I, when I was erect,
«speak to me a little to help me out of error:

Where is the ice? and he, how is he fixed
so upside down? and how, in so little time
has the sun made the passage from evening to morning?»

And he to me: «You imagine that you are still

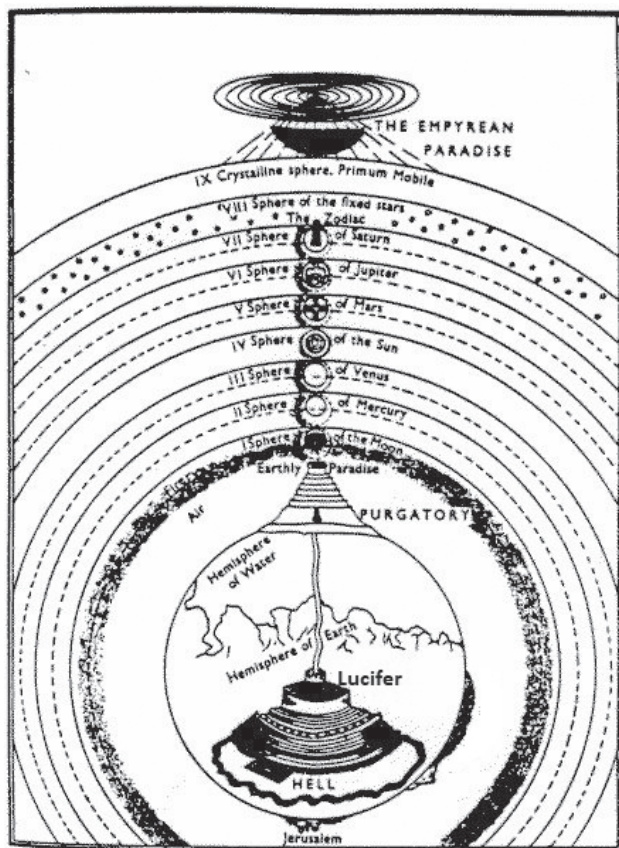


Figure 1. Schematic picture of Dante's travel described in the *Divine Comedy*.

on the other side of the center, where I laid hold
on the fur of this evil worm that gnaws the world.

You were on that side while I descended;
when I turned, you passed the point
toward which the weights all move from every direction.]

The narrative trick of the illusion of moving back instead of passing through the center (so that Dante cannot realize why he sees Lucifero reversed, why he cannot see the ice of the Giudecca again, and why he suddenly sees the light instead of darkness) is really a clever way of explaining centripetal gravity force. It is not easy to understand the first time by a lay reader, but is undoubtedly effective in order to stimulate the imagination. Dante also explains quite clearly what happens when moving from the northern to the southern hemispheres with regards to daylight and darkness. In short, Dante once again shows an effective use of storytelling in order to make important scientific knowledge popular, while at the same time respecting the metrics and the use of rhyme.

CONCLUSIONS

In this article we described and commented on several passages taken from the *Divina Commedia* by Dante Alighieri which deal with Medieval science. We started from experimental physics (an experiment of optics) and ended with theoretical physics (description of gravitation), running the gamut of alchemy, geometry, arithmetic, logic, meteorology, chemistry. Such concepts and methods are described by Dante through a narrative device, or storytelling, as well as dialogs between Dante and his tour guides (whether Virgilio or Beatrice) or the souls he encounters during his imaginary journey to the afterlife. Hence, we believe that Dante can be seen as one of the first, and most important, science communicators, or, in current language, a *testimonial* or an *influencer*, communicating the importance of scientific knowledge (see also Gilson, 1999, 2001).

Science communication has a rich history related to long traditions and cultural factors, which are now embedded into more extreme forms like *science outreach* and *public engagement*, that is, the set of activities and events designed for the dissemination of research results and scientific knowledge in general among people. Osborne and Monk (2000) provide an overview of key motivations for science communication. First, there is the utilitarian argument, which states that people involved will gain technical skills and knowledge that will be useful to them. Secondly, the economic argument posits that advanced societies require a technologically skilled workforce and, at the same time, the results of research funded by Government or other institutions must be explained to financiers. Thirdly, the cultural argument claims that science represents a “shared heritage” and it should be recognized as a wide part of our culture. Finally, the democratic argument asserts that science affects most major decisions in society, therefore it is important that both politicians, managers and citizens are able to interpret basic scientific information. Dante was mainly motivated by the democratic argument, however even the economic argument can be considered relevant to his time as the emerging classes involved in economic activities needed to increase their knowledge.

Of course, even nowadays not only scientists, but also scientific journalists, writers and intellectuals in a broader sense contribute to reaching such goals (see e.g. Capozucca, 2017).

Dante Alighieri was very active as a science communicator, as he clearly outlined in the *Convivio* and *De Vulgari Eloquentia*. The pioneering methods he used to diffuse knowledge among people were not only aimed at involving non-academics, such as the emerging classes

of merchants, traders, artisans and bankers, but they also included illiterate people.

In order to appreciate the extent to which the methods for science communication used by Dante in the *Divina Commedia* are modern and forward-looking, we propose two short passages from two contemporary well-known Italian writers. The first one was written by Umberto Eco in the weekly Italian magazine “L’Espresso” (April 28, 2005):

A seasoned belief wants things to be known through their definition [...]. I am among those who believe that even scientific knowledge must take the form of stories. [...] our knowledge (even the scientific one, and not only the mythical one) is woven of stories.

The second one is taken from a letter written by the Italian writer Dino Buzzati, addressed to the intellectual, poet and engineer Leonardo Sinisgalli, founder and director of the magazine *Civiltà delle macchine* (house organ of Finmeccanica, the main Italian group of firms dealing with advanced mechanics, robotics etc.) where the letter was published in the January issue of 1956, p. 78:

In *Civiltà delle macchine* the scientists and technicians speak as technicians and scientists as if they were addressing people of the same level, they don’t smirk, they don’t soften their voices, they never have the air of saying, “Things are much more difficult and complex, but for you, stupid and ignorant people ...”. The normal rule of science popularization is that scientists stoop to readers’. Here it is the reader who rises.

As argued several times in this article, both these modern points of view can be found in Dante’s pioneering dissemination work, thus confirming his role as modern science communicator and his enduring legacy 700 years after his death.

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