Encounters with Science: Dialogues in Five Parts*

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Preface

In our time Science gets its prestige from many successful applications and now cohabits peacefully with religion and philosophy, with political power, with the general public and with the media. In this situation Science appears as a respectable whole and a certain decorum is required to alleviate the fact that science may be very difficult to understand, that scientific work can be dull and insignificant and that many branches of science have very different goals, methods of research and criteria for acceptability.

In the dialogues of Encounters with Science this decorum is broken in all the cases of cohabitation above. The only aim of the author has been to encourage reflection and sometimes to amuse.

The text has five parts. The first is called Mathematics, Life and Death and is a miniature play in two acts about the mathematician John von Neumann's adventures in heaven and hell. In the second part, called Ghosts, Charles Darwin and Henri Poincaré reappear to discuss science after their time. The third part, called the Soul of Science, features Lady Scientia, the guardian spirit of Science, talking to Common Sense represented by Simplicio, a character from Galileo's dialogues. In a rambling encounter they discuss the conflict between common sense and certain parts of physics, applied versus pure science and the recent industrialization of science which puts a great burden on Lady Scientia. In the next dialogue Lady Scientia is free to express her views to the press in an impromptu interview. The definition of the word science is settled in a discussion between two contemporary young students aspiring to their Ph.D's. In a fourth part, entitled The Prince, political power appears in person as the ruler of Syracuse talking to Archimedes and in a dream a

* Lars Gårding was expected to speak at the conference, but unforeseen circumstances arose at the last minute and he was unable to attend. We are pleased to present his contribution, which consists of several dialogues on science and mathematics as well as their interaction with philosophy, religion, and society.

present representative talks to the press about science. The fifth part, Communication, features a duel between science and the humanities, a section on metaphors and a piece on how to appear in the media.

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MATHEMATICS, LIFE AND DEATH I

1 Von Neumann and God

A simple space with a background through which the actors can disappear. A table and two chairs. Characters: von Neumann (N.), a world famous mathematician, God (G.). A conversation in heaven. No music. God is sitting at the table. Von Neumann enters through the curtain.

G. Welcome John von Neumann. Please sit down.

N. Thank you.

G. How are you?

N. Better than when I was in the hospital. And yourself?

G. I am well, thank you. I have decided to be well. I am almighty, you know.

N. Who are you?

G. God.

N. That sounds strange. Tell me more. Might you be the God that is mentioned in the Holy Scriptures?

G. The same. In human form.

N. Then perhaps you know all future mathematics?

G. Yes, but I let mathematics evolve by itself. It is more entertaining that way.

N. What is my work in logic worth? No one quotes me any more.

G. As I said, I let man deal with appreciation and disdain. Here, among us, a higher logic prevails, a logic not accessible to man. I advise you in your new, more tranquil circumstances, to take your time and see what happens among men. If they discover inconsistencies in mathematics, that is their business. One can do no more than regret not being present at such interesting events.

N. My first ambition in life was to make my mark, and then it was a matter of being of use and taking thinking as a diversion. I was never calm and happy.

G. That was never my intention with mankind.

N. I wrote down the axioms for Hilbert space and afterwards I felt them as a constraint. My rings of operators became nothing more than a catalogue of possibilities. I wanted to do something new but I was only partly successful. I intended to create logical system that would cover the activities of the brain, but I did not have time to develop it properly. I was interrupted by my illness. My life ended prematurely If you are who you say you are, then all this is your fault. Why did you not let me live?

G. My omnipotence is often delegated to chance. Otherwise there would be much too much to do. It was chance that you were born and chance that gave

you cancer. I watched and did nothing. You understand that I have more to keep an eye on than your affairs.

N. What for instance?

G. Everything that happens, will happen and has happened. The well-being of mankind, the smallest insect and so on.

N. Yet you seem to take things easy.

G. I am dealing with you just now. What are your views on the deepest questions of mathematics?

N. Unlike Wittgenstein for example I have never had a desire to let fundamental questions disturb my peace of mind. In mathematics I am an opportunist. So many wonderful things have been done, and so much has been understood. An occasional philosopher sometimes protests about our way of understanding, but since philosophers question everything one does not have to take much notice of what they say. They never have a proper set of axioms.If mathematics should contain a contradiction it would only be in the outer areas of the subject and could be corrected by small changes. That is my point of view. I am an opportunist. (*pause*)

There is, by the way, something strange about the attraction the so-called ultimate questions hold for people. They know nothing about mathematics, yet they are concerned about the subject's validity. This sometimes takes grotesque forms. My colleague Gödel spent days answering letters about his incompleteness theorem. He had to explain that it did not address eternal truth or the existence of God (you'll excuse me I hope) but a certain way of numbering the propositions in a logical system.

Those who got in touch with him had a fundamental religious longing for a life that was a blessed, eternal holiday. Do you have a comment? You may not be entirely omnipotent, but you seem to think and have opinions. What do you think about mathematics for example.

G. I *am* omnipotent, but as I have already told you I can delegate my omnipotence. One reason for doing so is that I don't want to get into logical difficulties. Total omnipotence means that I should have almighty power over myself, and then I would be both almighty and not almighty. That is a logical paradox that would have incalculable consequences. On this point you as a mathematicians would understand me far better than many others. I must say it feels good to have such a competent partner in conversation. And now, if you will allow me, I shall answer your questions in detail. They relate to matters of great concern to me.

My omnipotence would be heavy burden unless I did not wholly or partly leave it to chance, to the forces of nature, to certain people, writers, artists, scientists and so on. Sometimes even the devil has a part in my omnipotence but, it goes without saying, within certain limits. In other words, sometimes I use my omnipotence, sometimes not. But of course I, myself, decide where

and when to use it. Anything else would be unthinkable. I enjoy my freedom, I must say. (*pause*)

You asked about my opinions. Yes, I have opinions or, more precisely, opinions have always been attributed to me. What they are now is in some doubt. It used to be easy: in my opinion man should be honest and upright, attend the services and have an unshakable faith in me and in Holy Scriptures. Now the only people I can really trust in this respect are the Muslims. I see religious life becoming degraded, although the opinion that I exist seems to be fairly solid. But none of this concerns me. People need me, not I them.

Then there is the matter of mathematics. (*solemnly*) He who guides the fate of the world cannot be an opportunist. I believe in a mathematics that is uniform and free of contradiction. But I can tolerate doubt in some people, particularly those you speak disparagingly about. I have sympathy for the uncompromising doubters. I may have them held up and admired for their spiritual attitude to the mysteries of science, life and death. For ever and ever. Amen.

N. Spare me your religious tone. Your way of combining faith and doubt reminds me of the late Wittgenstein. Were you influenced by him?

G. I am not influenced by mortals. On the contrary, they are influenced by me.

N. Let me return to mathematics. Is Riemann's hypothesis true?

G. Yes!

N. Then give me the proof.

G. I see the proof at a glance. It would take too long to translate it into English or Hungarian. You will have to accept that Riemann's hypothesis is true.

N. You must be joking. Give me the proof!

G. I am not joking. If you continue to make trouble I have angels that can carry you to Hell. Do you long to be there?

N. (*agitated*) Give me the proof!

G. You can kick up as much fuss as you please. It doesn't worry me.

N. I must know if you are bluffing or not. Do you understand why quantum mechanics contains so many troublesome infinities?

G. Understand! Of course I understand. When I created quantum mechanics I was not in best form, but it hangs together.

N. Your answer is ridiculous. I find it more and more difficult to believe that you are God.

G. We will not come further with your questions. How do you want your life to be here in My House. Do you want something to do? The position as a heavenly meteorologist perhaps?

N. I should want a closer description, please.

G. Our meteorologists take care of the weather on earth. I employ an angel to pour water on the earth, another one takes care of snow and, sometimes, hail. I have also an enormous angel who blows and cares about the wind. But all these tasks are taken care of. Weather here in heaven is completely predictable and everyone knows how it will be. You could perhaps make it more equal weather on earth. But within limits of course. I offer you this position.

N. I do not want it. Can't I be a mathematician? I am a mathematician.

G. That is impossible. All mathematics here is within me and I never put anything in writing. I have even banned all writing. Everything has to be communicated orally and in small amounts. Heaven could not survive the restless systems that prevail on earth. We must lead ecological lives in the heavenly sense.

N. You are not God. I have heard too many contradictions already. You pretend to understand everything and know everything, yet you have a ridiculous and contradictory system for weather on earth. It is impossible for rain, snow and hail to be arranged as you say. Either you are an impostor, a vulgar impostor, or you are just making fun of me.

G. I am not making fun of you. I am God. Not an impostor. And to show you, I will have it thunder. Go, thunder! (*A terrible noise is heard*) Be careful!

N. You do not scare me. I am leaving. (*Walks away, but bumps into an invisible wall. Tries in vain to find a way out.*)

G. You shall not go away. I will stop you. (*N. Makes further, more half-hearted efforts to leave. Finally he sits down.*)

N. (*somewhat out of breath.*) I still think that you are a fake. Where are your hosts of angels, where is paradise, where are the archangels, where is Gabriel? Where is Jesus? Isn't he supposed to sit at your right hand?

G. Those you seek exist in my head. I myself can see them and hence have them exist whenever I want. People who think of heaven as a copy of earth have no imagination.

N. You make me more and more confused. Where are we?

G. Here, here!

N. Where is here?

G. That is unspecified. Since we are talking so much it is impossible to determine at the same time where we are.

N. Do you refer to the indeterminacy of quantum mechanics?

G. Not exactly, something similar. (*Both are silent for a long time*) Perhaps we should make peace with each other. You like to think. Let us think together.

N. I do not mind. (*Both adopt a thinking pause. There is a long silence.*)

N. What did you think about?

G. Everything, an endless amount.

N. Can't you take something out?

G. I don't want to. It would destroy unity. For me everything hangs together, my thinking is holistic. What have you been thinking about?

N. About primes. Without the prime number structure of the integers Gödel could not have done his numbering.

G. I'm sorry?

N. The integers are 1,2,3,4,5 etc. According to a famous mathematician, Leopold Kronecker, you created them. Is this true?

G. Of course! Please continue!

N. Certain numbers are products of other numbers except the number 1, some do not have this property and they are called primes. For instance: the number twenty which equals five times four is not a prime, neither is four but five is a prime as are two and three. The first primes are 2, 3, 5, 7, 11, 13, 17, 19, 23, ...

G. (*interrupts*) Yes, yes, I see then all: 29, 31, 37, 41, 43, 47, 51 (*a discrete cough from von Neumann*), no that is three times seventeen, 53, 57, no, that is three times nineteen, 61, 67, 71, ... (*This sequence is pronounced more and slowly*).

N. (*interrupts*) Stop! Stop! Your counting will never end. There are infinitely many primes.

G. I know that very well. I see all of them at a glance.

N. This I cannot do. But I can prove that there are infinitely many primes. The method runs as follows. Take any primes, multiply them together and add the number 1. The number that get in this way is either a prime or a product of primes neither of which is a member of the first ones chosen. However many primes that are listed, there is always at least one more.

G. Do not ever lecture me! Use figures!

N. Two times seven is fourteen and fourteen plus one is fifteen. Fifteen is five times three. Simsalabim! Out of the primes two and three the method produced the primes three and five!

G. Very clever. And new to me.

N. The proof is two thousand four hundred years old.

G. But when, like me, one understands and sees everything, proofs are becoming things of secondary interest. Other things take up my time. There are so many services and prayers to hear. I listen a little absent-mindedly but I cannot disregard sometimes fervent prayers. Although I am omnipotent I have to take in consideration people's conceptions of me. I cannot appear to be too stern and forbidding.

N. Your existence and conditions on earth means a contradiction which is usually called the problem of evil. Your are all-wise, all-mighty and all-good.

How does that square with illness, suffering, sin and evil, sudden death on earth?

G. It pleases you to make fun of me. You have seen for yourself that I have threatened you and restricted you against your will. I am not good all through. The one who created the universe and life and death on earth is not good and cannot be good. — With your mathematical jargon I could say that the problem of evil is wrongly put. Talking of such things I was once much amused by Leibniz's solution of the problem of evil, that man lives in the best of all conceivable worlds. There is only one catch with that. Who is doing the conceiving, he or I?

N. I admire Leibniz as a mathematician, but he was above all a philosopher. What are your thoughts about philosophy?

G. I have nothing against philosophy except that it is sometimes very tiring. But not dull! I must say that philosophers with a strong faith who have not questioned my wisdom or omnipotence have often performed interesting pirouettes in their thinking. But in the end they had to allow unproven ideas to avoid conflict with the human reason. Divine reason sees no such limitations. For me it is the question of seeing the whole picture and not getting caught up in details. By creating reality I gave the philosophical concept of reality a meaningful content. And if one keeps to existence all logical problems disappear.

N. Your own existence is a logical problem. If you are part of reality you exist and if you are not part of reality you do not exist. Since you created reality and existence you cannot yourself exist provided you have some kind of identity. It is not true that all problems disappear if one keeps to existence.

G. I exist, that is obvious. And I have not created myself. I'll have no hair-splitting here, please!

N. The inescapable conclusion of you having created existence is that you do not exist. And if you exist you have not created existence.

G. But I am sitting here and you see that I exist. And I created everything!

N. You do not want to understand. But I still keep my human reason. Is that some oversight on your part?

G. Not at all. In fact, man's struggle with logic amuses me.

N. But it does not amuse me to play a kind of clown for you. I have thoughts of my own that you cannot see through.

G. God forbid! But I am a little uncertain.

N. Let us abandon philosophy and pass to mechanics? Are you conscious of the sun, the planets and the comets?

G. This is the second time that you are trying to make fun of me. There is only one answer to your impertinent question: of course!

N. Do you remember how it was like to create the solar system?

G. Remember! For me time and space are no boundaries. At the creation I said 'Let there be light' and then on the third day or perhaps the second the solar system came into being when I created the large heavenly lights. I said 'Let there be the sun and moon and stars'. Genesis does not say much more but I have always thought that this book is too short to do me justice. I remember for sure that I also created the lesser but moveable heavenly lights. I said 'Let there be planets'. Then I could see everything from my elevated vantage point. How the earth and the planets move among themselves, around the sun and around me. It was a grand spectacle. I changed nothing because I thought the result good.

N. How about gravitation?

G. What do you mean? You speak in riddles.

N. The rotation of planets around the sun follows from the principle of gravitation. In the mathematical model for the planetary system it is assumed that two point masses are attracted to each other by a force that is proportional to the product of their masses and inversely proportional to the square of the distance between them. This law and the principle of acceleration determine the future movements of any number of such masses when their positions and velocities are given at some point in time.

G. This sounds good, but what is mass and so on.

N. That can be explained but the point is that the movements of a planetary system can be summarized and explained by a simple mathematical model. You said 'Let there be so and so' and the result is governed by a simple principle.

G. I could understand what you just said if I wanted. I am not stupid, you know. But I am more surprised than interested. Did you find all this out?

N. No, the culprit is Isaac Newton three hundred years ago.

G. Well, well,... Now I remember. The philosophers made me a clock maker who created a mechanical universe that goes by itself. That was an insult!

N. Gravitation made it possible to understand the movements of the planetary system. And this was tremendous success for theoretical physics. And Einstein's relativity theory made it even better. It cannot be formulated as cause and effect, only as a variational principle. I, and many with me, consider variational principles to be the innermost foundation of the universe. What is your opinion? Do you have one?

G. Maybe, but please realize that I understand *everything* and need not reveal anything. Too much science disturbs the harmony of the universe.

N. You say that you understand, but what is meant by understanding?

G. To see without details is the Almighty's way of understanding.

N. (*ironically*) Brilliant? Perhaps you can teach me to understand in this excellent way?

G. I warn you. Irony has no place in heaven.

N. (*still ironic*) Why did you not make the creation more systematic and scientific. You could have started with the chemical elements. You could have said 'Let there be Helium, let there be Lithium, let there be Beryllium, let there be Boron, let there be Carbon' and so on. Or in order not to be long-winded you could have said simply 'Let there be a Bang'.

G. I'm sorry?

N. According to one theory the universe was created in 3 seconds from concentrated energy by an explosive expansion, jokingly referred to as the Big Bang. The chemical elements were formed as well as nebulae, milky ways and so on. Universe as we see it now.

G. You are beginning to go too far. Finding fault with me about the creation! If things were as you say, I was the Big Bang. But creation has to be understood by people without education. So I chose to begin by floating above the waters and speaking in pictures to man in man's way.

N. (*seriously*) You are wrong to place rhetoric over science. Mathematical models are the best way to understand nature. Such models are especially sharp and completely successful in many important cases. But that doesn't mean that they cannot fail or be applied badly. All of them were created by man.

G. Ahh, now you are not so sure!

N. (*enthusiastically*) Our knowledge is temporary but sure in important areas. Relativity theory, quantum mechanics, light and electricity have been combined into a wonderful unit whose predictions have been verified a thousand times by experiment. We are on our way towards understanding the structure of matter. What is still missing is a theory that includes gravitation also. (*ironically*) But you who are omnipotent and knows everything, you could perhaps help us?

G. I will not hear your prayers. The answer is no.

N. Why?

G. It is very rarely that I motivate my nos. But now I will make an exception. I created man and I am loyal to him. What you speak about is understood by a very small minority. I must be understood by many and look after so many details, both small and large, precise and random, that I have no time for mathematical models. At best as a pastime. Philosophy as a hobby. The welfare of man is my major task. My view is holistic.

N. (*furiously*). You say that you understand but now it is I who really understand what is happening. In our conversation you have tried to adjust to me. You have pretended to understand and always replied to me in everyday language.

At the same time you have no idea of the laws of nature that govern both you and all others. And you also pretend that man's welfare is your

main task. Incredible. Everyone suffers and dies under your welfare and, like me, most people die too soon and in terrible fear. Your omnipotence is an illusion without substance. Your Heaven is a quiet Hell, a reflection of a more interesting hell on earth.

But you have no intellect. You simply mirror the person who is talking to you. You believe that you are God, but you are an apathetic witness to the miracles of nature and life. Man created you. It is men's desires and fears that are portrayed in you. The result is difficult to tell apart from another figure. I mean the Devil.

G. (*calmly*) You blaspheme and that is no good to either one of us. Our conversation has not been uninteresting but now it is finished. (*G. disappears into the background by a light effect. N. Is left alone and waits for a long time, mumbling and gesturing in a way that first expresses fury and triumph and then doubt. Finally a voice is heard: 'John von Neumann is granted an audience with the Devil.'*

Curtain

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MATHEMATICS, LIFE AND DEATH II

2 With the Devil

Same scenery as in Act 1 with a table and two chairs but no curtain of light. A dark backdrop from which the actors come and go. The actor who played God can play the Devil. Characters: von Neumann (N), the Devil (D), Immanuel Kant (K), David Hume (H), Aurelius Augustinus (St. Augustin) (A).[2] *D sits alone by the table, N enters.*

D. Please be seated.

N. Thank you (*sits down*).

D. How are you?

N. I was very excited but now I have calmed down. Who are you?

D. I am the Devil himself.

N. How am I to know that?

D. You have to believe me. (*Thunder is heard*). Up there HE is trying to prove his identity. I can't use the same means. Only a round trip in Hell could convince you, but we have a lot to talk about before it is time for that. Of course I know that HE sent you here.

N. Not directly. God disappeared and then someone called out that I had to go to the Devil.

D. Everything happens by HIS will. Most people come here directly. A detour via Heaven is actually very rare. I am supposed to have been there before the Fall but total oblivion was part of my punishment. So I have no memories of the place. I hope you excuse me if I now ask you some questions. What is it like in Heaven?.

N. I do not know. I had a conversation with someone who said he was God. This might even have been the case but not in the way that he thought.

D. But how was it? How did it all look? Was it hot or cold, were the streets paved with gold and did you hear singing and dancing day and night?

N. I sat at a table, about the same as this one. I was prevented from going away. When I asked him about Jesus and the angels he said he had them in his head.

D. It is clear that you have seen very little.

N. God lives in an illusion of omnipotence. He says that he extends it over you.

D. Unfortunately.

[2] A.'s polemics against the Pelagians is used in the conversation between A and N

N. When I accused God of being a phantom created by human yearning and fright he disappeared and I woke up here. Are you also going to leave me?

D. No, never. I have to arrange things for you. Do you have any wishes?

N. I would prefer a quiet existence where I can think about mathematics.

D. Existence!? For you existence is finished.

N. I do not believe you. In your house small devils torment small sinners with tongs and the greater ones are burning for ever.

D. There may be some truth in that but here with us there is no time and without time there is no existence. Everything here goes back and forth in time. Everything happens both simultaneously and not simultaneously. It is this that makes Hell what it is.

N. If you can make time go backwards, you can perhaps arrange for me to be born again. On earth of course.

D. This is impossible. Such power is out of the question for me. Time order cannot be controlled.

N. If time order is indeterminate, what about logic and mathematics? Are they possible in hell?

D. Not entirely, it is only the law of cause and effect that ceases to have a meaning...

N. But we are engaged in a normal conversation taking turns to speak?

D. This can only happen in Hell's ante-chamber where we are now.

N. Let me never leave this place.

D. This is impossible. I must lead you further on into Hell.

N. What are my prospects? If prospects exist here of course.

D. So far you have one thing to do. To talk to interesting persons. You are even sought after. HE has spoken to you and therefore many people want to air their thoughts with you. Rumours of your conversation with HIM are widespread. And we have many interesting characters in Hell's antechamber. Some are here for ever, others who have tired of the other place are here for shorter or longer periods. A kind of vacation you might say. Whom do you want to see? Here in Hell we use telepathy to make people meet and exchange views. I hear that Immanuel Kant wants to talk with you. Heaven disapproved of the tone of his philosophy and that is why he is a permanent guest here in the antechamber of Hell. He did not go further since his life was without reproach. Ah, here he comes. (*N. rises*)

K. A good day to you, Professor von Neumann, it pleases me to be able to talk to such a prominent mathematician. May I first ask you not to bring up the phrase 'Das Ding an sich' in our conversation. I write in my book that this notion is meaningless but this has not prevented philosophers from forever asking what I mean by it. Unfortunately I cannot prevent them (*makes gesture*).

The foundation of my philosophy is that all search for truth must depart from some basic assumptions, or, to use your language, axioms. Otherwise one is lost in a mire of senselessness.

N. I agree with you completely.

K. Could you please be kind enough to explain to me Gödel's theory of undecidable propositions. Here I only hear unreliable rumors and, so far, I have not had the pleasure of meeting Professor Gödel personally.

N. In your own treatise *Kritik der reinen Vernunft* there are four antinomies...

K. (*intercedes, speaks slowly in a professorial manner*) Of course, in the first one, two opposite theses are proved, namely that the universe has a beginning and is finite in extent and, the opposite one, that universe has always existed and extends indefinitely. In the second antinomy I proved that everything is composed of simple parts and also that everything is not composed of simple parts. In the third antinomy it is proved and disproved that everything happens according to the laws of nature and, finally, the fourth antinomy proves and disproves that there is a being which is the cause of everything that exists or happens. All this of course with the greatest brevity. As I say in the book, all proofs are conducted with the utmost care and in the greatest possible respect for the truth.

N. This I do not doubt. In our time your proofs would have been more formal but with no essential changes. The answer to your question is now simple: Gödel's theorem says that every complete logical system must contain at least one antinomy.

K. And what is a complete formal logical system?

N. Like geometry. One proceeds with axioms and logic and leaves nothing out.

K. That was an excellent answer. I am very grateful.

N. I believe that our ways of thinking agree in other ways. Do you not agree that one has to distinguish between reality and thoughts about reality?

K. (*Enthusiastically*) This is my great discovery and my consolation now that I am condemned to the antechamber of Hell.

N. I believe that God is created by the thoughts of humans, by their fright and yearning.

K. I could not go that far. I lived in another time. But let me embrace you. (*K. and N. embrace, exit K.*)

D. A pity that you two finished. Your conversation started off well and lasted long. But look, here is David Hume.

H. I can only regret that Herr Kant was after my time. If we only had been contemporaries, I could have disproved his Prussian phantasies and rejected them with great force. (*Turns to N.*) Who are you?

N. John von Neumann, 1903–57, mathematician.

H. Since I reject the existence of the outer world you simply cannot exist as a philosophical subject.

N. Very interesting. When I proved to God that he does not exist he answered me very simply. He said: But I am sitting here. I can answer you in the same way: I am standing here.

H. This is because I am looking at you. If I turn another way, your existence ceases.

N. But there are so many viewers. Hence everything oscillates between existence and non-existence in an uncontrollable way. Things are and they are not.

H. This is an inescapable consequence of my theory. It could be possible that God sees everything and this gives existence a certain permanence. But this argument belongs to the advanced parts of my philosophy. Anyway, you bother me. What are your credentials?

N. My mathematical theorems are well known and they are used every day.

H. But I do not see them and hence they do not exist.

N. But, Mr. Hume, mathematical theorems do not form a part of reality. They belong to thought and those who use them give them life by thinking.

H. Things are real only through a viewer. That is final.

N. But mathematics is more real than reality. Ideas are more real than reality. As you know very well this was the view of the famous philosopher Plato and it is in fact the cornerstone of his theory.

H. You forget that my philosophy is later than Plato's and hence more true.

N. Maybe you also deny Descartes' famous dictum: I think and hence I exist. In my philosophy I changed this to: I think about something, hence it exists. Besides, I cannot agree with your idea that one philosophy falsifies all earlier ones. If you really accept this as true, all philosophy from the twentieth century is superior to all earlier philosophy including your own.

H. Your philosophy!! Nobody heard of it.

N. This may be true but since I think about my philosophy, it exists. (*A pause*) It would be interesting to hear your views on the law of cause and effect. About this I had a most interesting discussion with Herr Kant.

H. Then you only heard some Prussian nonsense. I see no causes, only extrapolations of observed phenomena. Everything is basically uncertain. The so-called laws of nature are only worthless guesses.

N. You do not seem to understand that there are degrees of uncertainty. That stones would not fall to the earth when you let go of them is extremely unlikely. I mean to say unlikely for the inhabitants of the earth. And this is what we are taking about I suppose. Or did you perhaps develop a special philosophy valid here in Hell or in Heaven?

H. Since I was considered free of sin, my rightful place is in Heaven but there all philosophy is forbidden. My short vacations in Hell offer me the only opportunity to develop a philosophy but time has been too short. It would also be a difficult task since everything here occurs simultaneously and not simultaneously. Our conversation must be about conditions on earth. For me it is very possible that stones do not fall, for instance when you do not see them.

N. Our views are too different for a fruitful conversation. You have driven scepticism to absurdity.

H. This is possible. I am not insistent. But I cannot change my convictions. It is too late for that. I want to take leave of you in a proper fashion and without ill will. My vacation is finished. (*H. bows and disappears into the dark backdrop.*)

D. (*sitting*) You two are too different for a really interesting conversation. But here comes St. Augustine. I have never seen him here before and he is such a holy person that I cannot stand his company. (*D disappears. In the conversation between N and A there is a slowly increasing irritation between the two partners.*)

N. Welcome Aurelius Augustinus. I look forward to discussing God's grace with you.

A. How do you know my name? I have come here to talk with a famous mathematician John von Neumann.

N. I am the one you are looking for.

A. I am here for the same reason as you. I have quarreled with God. For a long time I have suspected that he does not draw a clear line against the Pelagians, those godless scheming vipers that were banned by the church. When I uttered my misgivings I was banished from Heaven and arrived here. For the first time. You know of course the Pelagian doctrine that man can find grace and eternal life through his own deeds.

N. I went to a good, old-fashioned school and therefore I know the Pelagian theories very well. Pelagius was a British monk. During his life on earth he acquired many followers. The Semipelagians had a theory that lies between Pelagius and what you consider is the correct doctrine.

A. Are there Pelagians left on earth?

N. I fear they are many but the word Pelagian is no longer in use.

A. Ah, that breed of vipers! I fought them with the sharpest tools of logic and quotations from the Holy Writ and I won brilliant victories. I did not live in vain!

N. Maybe. Would it be impolite to remind you of the victories of the Pelagian doctrine on earth? Pope Urban II promised forgiveness of all sins for those who joined a crusade to liberate Jerusalem. Later forgiveness of sins could be

bought for money. The riches of the church come from those who gave large sums for forgiveness of sins and a place in Heaven.

A. I know but still I did not live in vain.

N. Of course I am not a Christian but when I start thinking about the whole question I am inclined to believe that the most logical position is that of a Pelagian.

A. Your position hurts me but since you are well versed in logic it is easy for me to convince you that I am right. God rules over the fate of man before and after death. Who is going to Heaven or Hell is decided by HIM.

N. (*Starts getting more and more impatient and impolite to A.*) Perhaps. But you cannot convince me if we do not start by accepting some axioms. Without axioms every logical chain is just senseless gibberish. This is also what Wittgenstein thinks.

A. I hear that you are made of the right stuff. I suggest just one axiom: God is perfect and rules Heaven and Earth.

N. I accept that. God himself told me that.

A. Let me first make the revolting assumption that Pelagius is right that man can gain eternal life by his own doings. But God rules over the thoughts and ideas of man. If he left part of these activities to man, he would not be perfect. As Paulus says: for by obeying the law no man is righteous before God. What comes from the law is the knowledge of sin.

N. You cannot bring in the word of Paulus. You must keep to the axiom.

A. Sorry, that was an old habit. I start again. We must make our axiom more precise at one point: only God is perfect. Then it follows that man is not perfect and that nothing that he does is perfect. Hence he cannot gain eternal life by his own force.

N. I object to your logic. Man can do things that are perfect.

A. Not in my logic! Nothing is partly perfect.

N. Yes, but I cannot accept that you change our axiom. You added the word 'only'. Please do not do that again. (*pause*) Let me change the subject a bit. How did sin come into the world? Do we not need an axiom about the law, hereditary sin and salvation?

A. No, and that is the advantage of my theory. God led man to his fall and the result was original sin. But God is perfect and hence he can do nothing without meaning. Of course I am referring to meaning in the sense of God, not that of man. His deeds are unfathomable but also perfect since God is perfect. God gives eternal life and a place in Heaven to some, but not to others. His name be honoured.

N. The honour was not part of the axiom.

A. But if we did not honour God he would not be perfect. Hence we must honour him.

N. We have not yet come to Jesus, the son of God.

A. Since God is perfect he has a son. Without a son he could not be perfect.

N. Should he not have a daughter, too?

A. (*angrily*) This I did not hear!

N. But death on the cross?

A. Through his son's sacrificial death on the cross God gave mankind the possibility of eternal life, a life that would have been Adam's without the fall.

N. Could not God have achieved this without sacrificing his son?

A. You talk like a miserable heretic. The ways of God cannot be fathomed.

N. Since God is perfect he must have created the Devil and all evil. Do you agree?

A. You talk as a heretic. I turn away from you with disgust.

N. But listen! The word perfect also means complete. God created everything did he not?

A. There is an abyss between God and evil. But I admit that what you say follows from our axiom. But remember that we are dealing with pure theory.

N. Do unborn children carry original sin? Must they be baptized in the womb or at conception to have the grace of God? Why should not conception itself be baptism? It is the work of God or is it not!?

A. Now you are getting insolent. You are worse than Pelagius himself. The church teaches that a child should be baptized within eight days. Otherwise it is eternally damned.

N. But how can you, a man, predict the ways of God? Eternity is God's realm.

A. That is no contradiction. God speaks through me.

N. Another axiom?

A. Do not be insolent.

N. Does man have a free will?

A. Of course. He can choose evil.

N. Does God want him the choose evil?

A. Of course not.

N. But there are men who have chosen evil. And this cannot happen without the will of God. Since God is omnipotent, nothing can happen outside his will.

A. God's omnipotence is fathomless.

N. It seems to me that you have constructed a God with exactly the same properties as Chance. Chance is unfathomable. Chance gives to one health and sickness to another. It gives happy lives to some and unhappy lives to others. Disasters happen by chance and also lightning from Heaven.

A. You speak as your reason permits you to. Chance is not holy and not perfect. Besides, your argument is old. Certain Pelagians wanted to replace God by Fate.

N. Chance is perfect. No one rules over chance. God could throw dice about admission to Heaven and no one would notice.

A. (*Ironically*) Perhaps you remember that our axiom says that only God is perfect. Hence Chance is not perfect.

N. You yourself added the word 'only' to our axiom. I never accepted that.

A. You may have a sharp mind but you are not a believer. I insist on the word 'only' in our axiom.

N. I am a believer in my own way. I believe, for instance, that you have chosen your axiom in order to counter other believers who think that God has properties that say something non-trivial about him. You say nothing that can be verified. In this way you are invulnerable but also empty. Your theory cannot be falsified. Hence it is empty.

A. You use words that I do not know. I understand the word falsify abstractly but how is it used?

N. To falsify means to prove that a statement is false.

A. What you say fits my experience. No one has proved me false.

N. That is because you have deprived your theory of God, grace, belief and doubt, every ounce of content. It can be accepted only by those who doubt their own intellectual capacities.

A. I am very learned and I have had a good standing through fifteen centuries. No one doubts my intellectual capacity.

N. I do, although my standing has lasted for just half a century.

A. This ought to make you cautious.

N. On the contrary. I am a seeker of truth. My human good sense says that the deeds of God cannot be separated from those of chance. Perhaps I should found a church for the adoration of Chance. This would be more honest than your pirouettes with the holy scriptures.

A. Blasphemer! Son of a viper!

N. God may send you to Hell for good. But one never knows. Maybe your stay in Heaven happened by chance. Or the opposite. No one knows.

A. I know one who never will leave Hell. You blasphemed and defiled God. But I did not.

N. (*Teasing*) You have told God that he is a Pelagian! God is a Pelagian!

A. Liar!

N. God is a Pelagian and you are an idiot!

A. (*Raging*) The only idiot around here is you, you son of bitch, God-defier, miserable heretic! (*A and N look threateningly to each other and start pushing*

each other and seem to start a fight. This takes a while but is disrupted by D. who runs onto the stage with a trident glowing at the ends.).

D. (*Out of breath*). HE has seen and heard everything. He wants to strike you with thunder. You are going to court immediately. (*N and A are forced offstage by D with the trident*).

D. (*Deposes the trident that sputters in a can of water. Sits down, calms down and starts a thoughtful monologue.*) To-day has been a troubled day in Hell. It is very rare that HE acts so directly here. Most people are more cautious than this Neumann. His logic did not help him. On the contrary. (*Pause*). But what did he say? Didn't he say that HE is created by man, by the fright and yearning of humans? Just think of it! HE should be a phantom created by the imaginations of humans? How crazy can you get? This is absolutely ridiculous! . . . But let me see now. What does it mean? That I would be created in the same way as HE. But of course not by yearning, only by the fright of humans. Their terror of torture and the ordeals of fire. This is a rather disagreeable thought. Something I do not really deserve. . . But there are consequences. If one wants to be logical. If HE and I and all the rest were phantoms created by human fear and yearning we can also be destroyed by humans. Suppose that the humans changed their minds or ceased to exist. That is a horrible thought. What then of us? No more eternal life, total destruction! No more Hell! Terrible! I must get rid of this thought! I shake it off! (*A short pause*) But it comes back. It is terrible. HE, I and everything here just phantoms that can go away any minute that the humans decide! No eternal life! No life at all! Total destruction! No,no this is just a nightmare! . . . (*Rises*) It may only be a nightmare but I am starting to feel terrible. Terrible!. What if it is true? (*Leaves the stage, starting to cry and calling for help from God*) Help, help! HE must help me, HE must help me. Help, help. . .

Curtain

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GHOSTS I

3 Darwin Speaks Again

Late at night a modern biologist (B.) is sitting at his desk busy with his computer. Darwin (D.) enters suddenly, dressed in the manner of the eighteen-sixties, and a rambling conversation starts.

D. Please pardon my intruding. The reason for my somewhat abrupt appearance is that there are certain urgent questions that I should like to discuss with you.

B. (*surprised*) Yes, yes, very well, but who are you?

D. I'm Charles Darwin, the one who wrote *The Origin of Species*. I hope I am not forgotten?

B. No, no, not at all. But you cannot be Darwin. He is dead.

D. In my experience death is a relative notion when it comes to science. How I came here I do not know but now that I am here I have an opportunity to satisfy my main curiosity. I am curious to hear how the theory of evolution developed after my time. And I should like to talk with you about the principles of evolution. I hope that your are willing to do that and that you are able to disregard the somewhat odd circumstances that surround our meeting.

B. I will do my best. For a start, please take a seat. And may I offer you a glass of sherry?

D. No thank you, I am neither thirsty nor hungry.

B. Please don't think that the great Darwin is forgotten. *The Origin of Species* sells rather well after 150 years. It is a classic and readable, too.

D. Thanks for the compliment. It surprises me.

B. There is even an edition with all your changes and amendments done after the first edition. All ordered chronologically.

D. I worked a lot on my amendments but I do not think they are worth this kind of treatment. I understand from you that my work is the subject of exegesis like a fundamental religious document. I regret that because I did not found a religion. On the contrary, I only gave strong arguments that past life on earth developed by natural evolution which is still active.

B. I read recently that you borrowed some of these arguments from a certain Mr Wallace.

D. As soon as I got to know Wallace's work I arranged that his work and mine were printed in the same issue of the Proceedings of the Royal Society. I did it at once!

B. But they say there was a delay of several weeks!

D. For the printing yes. But not otherwise. I am a gentleman.

But let me come to my question. When I wrote the book I used the term Natural Selection. I argued that it exists as a mechanism but it does not predict the course of selection. Later I adopted Herbert Spencer's catchword '*The Survival of the Fittest*'. I thought then that it was a good summing up. But I do not any longer think that. Which species survive? The fittest ones of course. But how does one distinguish the fittest species from the others before they survive or die out? Also fitness is never constant. It is always fitness with respect to environment and the fitness of others and these conditions change all the time. If you try to predict a bit of the future from some observed fitness of a species you must take so many things in consideration that prediction becomes hopeless. If you try to think over what it means, Spencer's catchword disappears into thin air. It is an empty tautology! Likewise if applied to individuals! It pains me that my fame may be based on a tautology. What is your reaction?

B. I agree that fitness depends on too many things. Some sixty million years ago a small asteroid hit the earth and destroyed with one stroke the fitness of big reptiles and created or improved the fitness of small mammals.

D. This is news to me but it illustrates the difficulties I just mentioned.

B. The survival of the fittest is now not taken seriously by scientists. But I must say that your book has certain other weaknesses. It happens many times that the author takes Nature's wonderful ways, for instance all exquisite adaptations, as an argument for Natural Selection.

D. I am conscious of that! But when I wrote the book I often took a fresh breath in order to resist this temptation. I regret that I did not succeed completely. But remember that the Stability of Nature— I mean the existence and stability of species— is actually questioned by the theory of evolution. The stability is a only a delusion caused by the short span of human life.

B. I agree completely with this view, but may I remind you what is said in the first edition about the appearance of workers in societies of bees and ants. You claim that Natural Selection makes fertile parents regularly produce both sexless and fertile offspring. This kind of reasoning is, if you please, just another reference to Nature's intrinsic ability to produce useful things.

D. I have a faint memory of this passage but I wrote it long ago and may perhaps be excused for small lapses in my big project. There are more important things to talk about.

B. I see your book as a plea that life on earth could not have developed by means other than Natural Variation and Natural Selection. What you say here could perhaps have been more easily accepted if the Bible had had a slightly different account of Creation. The phrase *and God saw all that he made and it was good* could have been *but God saw that not all living creatures that he had made were good and he struck the bad ones with lightning and concealed them in the earth. And he made new creatures until he found everything good.*

D. But then it would be said that my theory is not new and I would have found it very difficult to get people interested in it. Fortunately the Bible says what it says.

B. In order to avoid every form of creation you assume that life has an intrinsic tendency to change. When this tendency has been active during a very long time, it has caused the appearance of new species from old ones. Evolution is like a tree with an insignificant beginning. Branch after branch appears, some die out, others develop new shoots.

D. That is not what I say. You are just replacing my long chain of arguments by a picture. But I admit that your picture is not entirely wrong. Note that I say nothing about the origin of life.

B. Well, let me have another go at your theory. Even though it can be criticized in detail no one else has a found a vision of life's development on earth that has the same convincing power.

D. I am pleased with that, but I think that my book is more than a vision. There are arguments. Please do not forget the chapter where I discuss and counter objections to my theory.

B. Of course I do not forget that. But please note my strong choice of words: convincing power.

D. I noted that. But please tell me about progress after my time.

B. Sure. In your time it was clear that acquired characteristics are not inherited but it was not clear how inherent characteristics are inherited.

D. Well, I knew something from my experiments with pigeons and there is an extensive experience of inheritance among men and from the breeding of animals.

B. Yes, but now we have new information. It comes from the interior of the living cell. There we find the inner inheritance mechanism of all life in the form of molecules that form chains and big complexes. Some hundred years ago such complexes were found and called chromosomes. We men have a certain number of them, women one more. When an egg is fertilized it gets half its chromosomes from the male and the other half from the female and then when the fetus grows, the chromosomes go into every cell of body. It is believed that they carry various genetic traits which control the formation of proteins in the growing body.

D. Only believed? Where are the details.

B. Much is known about the chromosomes of the much studied fruit fly, but for man, for instance, one does not know any details. But now, let me continue. After the chromosomes one has found similar and simpler molecules, called DNA for short. DNA is a long molecule which has the form a double helix which becomes a ladder with steps when unraveled. Each step consists of two molecules called a base pair. There are only four kinds of base pairs (two if you disregard the order between the molecules). If you represent each of them

by a letter you can visualize DNA as a very long word consisting of only four letters. This word is unchanged when the cell divides into two because then the ladder is cut lengthwise into two parts, each having the ability to create or assemble a copy of the missing half. My description is a bit unorthodox but I hope it is clear.

D. I can understand the helix, the ladder, the splitting and the copying that gives new DNA for new cells but my understanding ends there.

B. But there is more to come. It is considered that DNA carries the blueprint for the growth and death of an individual. Your DNA reassembles mine as two individuals of the same species do but they are not identical. Your DNA suffices to identify you. And this is used by the police

D. By the police, indeed! There must be better reasons. How was all this discovered?

B. By a new microscope leading to a new form of biology, microbiology. There is also molecular biology. The various chemical substances and proteins can be seen if a mixture is soaked up in porous material. Then they produce different patterns. There are also other methods. I cannot give any details here.

D. All right, but what do these discoveries mean?

B. DNA is a very long molecule with thousands of base pairs but they can be grouped into something called genes. The sequence of all genes is called a genome. Every species on earth has its genome and is characterized by it. But the details vary between individuals.

D. You seem to give me only formalities. Every species on earth is characterized by many things, not only its genome. And there are always differences to be seen between individuals.

B. Sorry. The genome is a blueprint for the life of an individual from birth to death.

D. Like a seed of a plant, maybe?

B. I do not know whether you are ironical or not. The cells of your seed contain the DNA of the plant. DNA exists in every cell. The novelty of the genome is that we may manipulate it. Inject new genes and so on. There are many details here. But there are high hopes that serious illnesses are caused by defective genes and may be cured by selective killing.

D. Interesting. But I am a biologist, not a medical man.

B. But I am glad you are interested. There is more to be said about the genes. We say that they carry information for the life of an individual in the sense, for instance, that the initial growth, the successive formation of specialized protein, is regulated by the genes.

D. Any proof of that?

B. Sure, it is possible to replace the genes of a fertilized egg by the genes of another individual. This has been done with sheep and the result has been two genetically identical sheep.

D. That seems convincing. But how many sicknesses have so far been cured by this genetical engineering?

B. You found the same word that we used. Genetical engineering. But its results so far are meager. Perhaps there is such a cure in one or two cases. But there are high hopes and much ado about it in the press.

D. Let me go back to the genes. I ask myself if they carry inheritable traits. It was a lot of talk about such properties in my time. For instance for horses. How to see if a young horse is going to be good at the race track.

B. The grouping of the genome into genes has to be done by chemistry and trial and error. They carry inheritable traits but in a complicated way. The traits that we can see of observe through action correspond to only a fraction of the genes found in DNA.

Let me also say something that I perhaps should have said at the beginning. DNA explains Darwinism. Chance variations of DNA differentiates between individuals and makes for different capabilities of survival and regeneration.

D. But this is Darwinism! What you say is that each animal and plant carries its own intrinsic quality, visible in all parts and characteristic of its species, but with individual differences. Darwinism began with this elementary observation and concluded from the existence of fossils that nature has evolved by Natural Selection.

B. You seem to have difficulties with the genes. Due to the discovery of genes, your intuition is now replaced by the chemistry of proteins.

D. Thank you, with your permission I still keep some intuition. But let me accept your genes for the moment.

B. Do you also accept that DNA and the genes constitute a more concrete foundation of Darwinism than what was known before? I mean that DNA is a source of variation which together with other variations, like chance of survival and chance to have offspring, explains Natural Selection.

D. I accept this as an alternative but you must understand that I can only see this as a confirmation of my own way of thinking.

B. I repeat that we only need to remember that the genes are in all cells and are copied to new ones, ...

D. (*interrupting*) We have been through all that!

B. Sorry.

D. Let us talk about evolution itself. Anything new there?

B. Well, the imperfections of the information process in the cells is the origin of the constant modification of living matter. When new forms appear, some have a better chance of survival than others and in this way...

D. This is just the survival of the fittest and not an explanation of the evolution.

B. But admit that what I say has the ring of truth.

D. Unfortunately. But how does one verify whether someone or something is fit for life? Except for very clear cases and short range predictions I think the answer must be a verification *posteriori* after many generations. If ever.

B. Please excuse me if I say that you knew nothing about the mechanism of inheritance and wrote very vaguely about variation. But we know this mechanism and see how its variation makes evolution possible. That DNA exists in all living matter supports the theory of evolution. It is true for all forms of life and explains why evolution proceeds very slowly and by degrees and through intermediate forms.

D. But that is what I said. Without your DNA. But does it explain the direction and adaptations of evolution?

B. DNA variation makes certain individuals better adapted to life than others.

D. There you go again. I have told you that the word 'adaptation' here means nothing. It just has a seductive ring to it. The same for the phrase 'fit for life'. What I mean is that when one writes and thinks about evolution it is too easy to burden the terms used, even the term Natural Selection, with some purpose. For instance that the object of evolution is to make better adapted and more beautiful living things. This may be a natural inclination of the human mind but that is all there is to it.

B. I will provide you with an example. DNA gave to the swift its fast wings and broad beak to make it fit for life at high altitudes where it can chase insects undisturbed by other kinds of swallows. This would have been impossible for the swift without its specialized equipment. I mean that I can use the phrase 'best fitted' in an extremely convincing metaphorical sense.

D. If you change DNA to God in your example, you get an old-fashioned, edifying example of the Wisdom of the Creator. Natural theologians used the same kind of stories when they described how everything in nature is well adapted to its purpose.

B. I do not want to abstain from my inclination to a bit of loose thinking. But I admit that you may be right from a strict philosophical point of view. But biology is not only philosophy.

I want to say one thing more about DNA. It does not change abruptly. Its complicated construction makes large modifications extremely unlikely.

D. But this is also my argument. Natura non facit saltum.

B. This is only a simple quotation. The Latin does not make it better.

D. But the argument is very explicit in my book. Evolution has progressed through intermediary forms. I quote: 'Natural Selection can act only by taking advantage of slight successive variations; she can never take a leap, but must advance by the shortest and slowest steps'.

B. You just guessed. DNA is an experimental fact.

D. I did not guess. Please do not be rude.

B. Sorry. But I insist that DNA is a program of the development of its bearer through life to death.

D. Everybody knows that inherited abilities are very important. More than that, maybe. But environment is also relevant. Now you are sitting over there overrating the importance of your DNA. An entire life program. No one with any experience of life can believe you. Someone falls off a horse and the life program is finished.

B. Sorry if I was not clear enough. I mean a life program which is not influenced by exterior circumstances. In certain cases one can see in DNA that a person carries the germ of an incurable disease which makes itself felt later in life.

D. And how is this possible?

B. As I said before it is possible to identify all kinds of protein, including the dangerous ones. May I remind you of the successful experiments that resulted in an exact copy of a sheep.

D. Doing that on a large scale one could make copies of human beings. To what purpose? What happens in the ensuing generations? We have always known the dangers of inbreeding.

B. Science must always advance.

D. But here backwards.

B. You ridicule respected, hardworking geneticists.

D. Sorry, geneticists?

B. After the laws of inheritance became known we got a science called genetics. Its practitioners worked to improve plants by crossing. Now they work with DNA in laboratories.

D. Crossing plants and animals is very old occupation. I have some experience myself. With pigeons. Moreover, I was a biologist working in the field. You talk about laboratories.

B. That is the direction the development has taken. Technical apparatus, powerful microscopes, electrical gadgets, still more powerful microscopes. And typewriters like mine here. It remembers and stores what I write and prints it on demand.

D. I can imagine all this but I do not like it. Are there no people who just think and write?

B. There are many, many of them and they work under orderly procedures. When I think that I have done something worth publishing, I prepare a manuscript and send it to a journal. There are hundreds to choose from. But only theoretically because every journal has anonymous reviewers who may accept or reject what I have done. Different journals have different standards and if I doubt the worth of my work I choose a journal where I am reasonably sure of acceptance. Since there are thousands of people like me who want to publish what they write, this means that people write too many scientific articles. Most of them are soon forgotten because what is written in them represents only a minute progress of science. No one is able to read everything and most of it leads to nothing. But, as you might have wished with your question, there are people think and write.

D. In my time science was an affair for a small number of gentlemen and I think that was much better. But let us leave all trivialities. I want to go back to my question about why the best adapted ones should survive. How is this in the light of your DNA. If there is some light.

B. No irony, please. I only tell you what I know.

D. Sorry.

B. Since the structure of DNA is known but not the exact way the genes rule the production of proteins it is perhaps best to take your slogan as a tautology. We can't foresee the effect of a small change of DNA. And if we could do that, we could not foresee a future environment. But in isolated cases like the following ones we could perhaps say something. A male pied flycatcher is attractive to females if its white forefront is clearly visible. You may imagine that there is a piece of DNA that is responsible for this white spot. If it changes to be more effective, all male pied fly catchers will in the end have bigger white spots on their foreheads.

D. Until they are white all over like pigeons.

B. I do not mean that. Some other development would take over.

D. Your example is the same as the one with swifts, only less poetical and less striking. But my conclusion is the same as yours. The effect of adaptation cannot be foreseen.

B. I admit that, but I am not ready to say farewell to my seductive explanations. By the way, they are very popular in biology nowadays. A biologist has written a book called the Selfish Gene. There he says that the gene has only one desire, to live on in as many generations as possible at the cost of others.

D. But the little molecule cannot possibly have desire in the ordinary meaning of this word.

B. You are too literally-minded. By gene the author means both the individual and the genetic information it carries.

D. I do not believe that this is true. A deer buck wants to breed only during a certain time of the year. The rest of the time it strives to stay alive. Every

living being strives to live on. That is the dominating instinct. Breeding comes second and only during certain periods. I do not like this author. Not scientific. I suspect that we have here another attempt to explain evolution as a result of Nature's inborn Wisdom.

B. Perhaps but in this it has to be taken as rather advanced. The author is well known and his thesis has invaded the popular biological literature. But I think he wrote the book to tell what biologists think about evolution. For instance that it admits altruism. Relatives do not kill each other because they share the same genes.

D. But it may as well be the environment. Relatives know each other and often live together.

B. I am not responsible for every opinion that I am telling you about. In any case there is always a tendency to ascribe a kind of wisdom to evolution. I once wrote a popular article about the altruism of birds. But I understand that it would not be of interest my guest. When all is said it perhaps best not to attribute any intention or superstructure to evolution.

D. Chance rules. This is also my view in the book. Don't you agree?

B. That Chance is supreme is perhaps not putting it exactly right. Chance is limited by everything that it has previously achieved. If it has succeeded in forming a stable species, there is not much room for Chance. I believe that it then can only do a little mischief in the DNA.

D. This is what I always thought, though I never mentioned the word DNA of course. There is something repugnant about the thought that our finely tuned Nature is the work of Chance. But nevertheless this thought must be faced and evaluated. This is what I did in my book.

B. To return to the beginning of our talk I want to say that our descent from the apes and the catchword 'the survival of the fittest' both have disappeared from scene. They are not taken very seriously and do not arouse any hard feelings any more. You need not have a bad conscience.

D. Thank you, I am not troubled by this any longer. But I am still not satisfied by my analysis. It should be more complete but I do not know how.

B. There is perhaps some consolation in the fact that you have analysed history, the history of the development of life on earth. Historians have the same trouble as we have. Few things are absolutely certain, evidence is almost always missing, experiment is out of the question and so on. The solution for them has been to write books where some coherent philosophy is applied to the history of some period. There are some master pieces of this kind of writing. And this is for historians an accepted way of doing things. So, if you excuse me, I think that it may be said that you have written what amounts to a great historical treatise of evolution on earth. If you consider yourself as historian you may perhaps be more satisfied and free of your (and mine) unfulfilled desires of more satisfying explanations of evolution in all its enormous complexity.

D. I did not think of it this way. Biology is not only history. It is a natural science where logic and strict reasoning is required and some prediction, too. When I think back on my writing I think it had a meaning. I was dissatisfied with what had been written about evolution and I wanted the truth. The truth is that life in all its forms has come about during a very long time without any plan or any general principles that we can see. This conclusion may impress one as trivial and insignificant compared to the theories of creation. But it is true.

B. But think of all sharp observations and arguments behind this truth.

D. Yes, but the result...

B. The task was too big, too many unknown entities were involved. The only possibility is a vision. The biologist cannot experiment over long intervals...

D. I wrote a chapter about instinct. It began without any definition of this notion. But in spite of that I managed to say a lot about instinct. It was a bit vague but not meaningless I thought. I believe now that man has an urge or instinct to explain everything. It is indispensable in daily life. You have to explain a lot of things, why it is deadly to fall from a large height, why a bull may be dangerous, why one should not be in the way of a four-in-hand in a sharp trot and so on. There are innumerable indirect proofs that this instinct exists. It commands its owner to find connections and leave nothing unexplained.

B. I think that your vision of life on earth is a beautiful result of this instinct. Nothing to be ashamed of. You satisfied your urge and many have admired the result.

D. So far we must be satisfied with that. But now I feel that I am no longer able to keep my earthly shape together. Goodbye.

D's body pales away. B. leans forward over his desk, putting his head into his hands.

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GHOSTS II

4 Hypotheses. A Discussion with Henri Poincaré[3]

A room with a desk and a computer. M., who is a medical doctor and a bit of a philosopher sits at the computer writing a letter. Suddenly the screen changes and is lit up by a message in capital letters: PREPARE YOURSELF FOR AN IMPORTANT ENCOUNTER. M. hesitates for a moment not knowing what to do. Then there is a new message: TURN AROUND! M. turns around and sees a small man in a black suit twinkling under his pince-nez. A conversation starts.

M. Who are you ?

P. Henri Poincaré. I died in 1912, for the moment I'm back from the other side. I have an important question for you.

M. Thanks very much. But which Poincaré? There were two of them, as far as I remember.

P. The other one, my cousin Raymond, was a politician, I am Henri, a French mathematician known for important papers in mathematics and physics. My three books about science made me known also outside the scientific world. I died after laying the foundations of a new branch of mathematics called topology.

M. I remember having heard about you. But mathematics is far from me. I am a medical man.

P. I come to hear about the fate of the hypothesis in the natural sciences. In my book on science and hypothesis I stressed the importance of hypotheses in these fields. Science is not all discovery. Hypotheses are guides for research and thinking in general. Fruitful hypotheses are sometimes as important as definite results. After a long time of reflection I now think that hypotheses are somehow universally useful. I should like to discuss this with you.

M. There are hypotheses in medicine but we prefer facts. With hypotheses we would come close to alternative medicine.

P. Your are talking about things I do not know. Please explain yourself.

M. Scientific medicine stands in opposition to charlatans that are often popular with the press. They have named their own activity alternative medicine while we are said to practice school medicine.

[3] In his booklet *Science and hypothesis, (1912)* the great nineteenth century mathematician and physicist Henri Poincaré reviews the great advances made in the natural sciences in his century which saw the birth of the theories of energy, electricity, light and radiation. All of them were first born as hypotheses. He concludes that the popular view of science as a series of uncomplicated discoveries is wrong. Instead it is the well formulated hypothesis that drives science forward. The wake of science is strewn with discarded hypotheses.

P. In my time quacks were also popular with the press. This seems to be for ever unavoidable.

M. Sure.

P. But what do you have against hypotheses?

M. They do not belong in medicine. There are plenty of hypotheses that would kill patients if taken seriously.

P. I wrote about hypotheses in the natural sciences. If you do not accept hypotheses our encounter is finished.

M. Even if I hesitate to use hypotheses in medicine, I am interested. I am a bit of a philosopher, too. We could talk in general terms. Please take a seat and let us just talk quietly together.

P. and have some hypotheses. By the way, it seems that you share the common misconception that a picture says *everything*.

M. I don't. I just described our various pictures, not the difficulties about them.

P. Sorry. Are you finished?

M. Not yet. We have also new drugs. The antibiotics can put an end to very many infections. In your time many died by pulmonary and other infections. Not so now. People die later in life by heart attacks and the like. Or cancer. We now know a lot about cancer and we can cure some but not all by radiation. Our diagnoses are now much better than before. We just send a sample of a patient's blood or urine and even a bit of tissue to a laboratory that makes an analysis and finds out very precisely what the illness is. The doctor reads the laboratory report, writes his prescriptions and passes to the next patient.

P. From what you say the work of a doctor could be done by an automaton. Anybody can be a medical doctor it seems.

M. No irony please. When I mentioned the word 'fact' in the beginning of our conversation I thought of all the tools from the natural sciences that help us to make a diagnosis. I went through the most important of them. They really are facts.

P. I can agree with you but with some hesitation. It seems to me that your pictures and analysis are facts only in relation to the rest of medicine which, I believe, must be a bit of what it once was, full of hesitation and guesswork.

M. Of course these features remain. We have many patients with diffuse symptoms or symptoms which we do not understand.

P. But then you cannot do without hypotheses. Without them you would be helpless and unable to decide a course of action.

M. This happens sometimes. There are of course cases where we can do nothing. But I should like to paraphrase what Molière's wood-cutter says about fagots. I mean that there are hypotheses and hypotheses.

P. Yes, if you like. But you must mean something more specific.

M. I mean that the hypotheses in your book are too special since they are only taken from mathematics and physics and the book was written at a period when these sciences were very successful. For me the word hypothesis is too big. In ordinary medicine we just suppose and guess and muddle around. If one drug does not help, try another one and so on. I remember that you said in the beginning that the word hypothesis is used about causes and connections. I have very little of that, just standard rules.

P. I think you have explained yourself clearly. I may have been too insistent with my hypotheses. Perhaps I have been too optimistic when it comes to medicine. I agree with you that there are hypotheses and hypotheses. But let us continue anyway. You have told me many interesting things and our conversation amuses me.

M. As I told you we can now see that something physical happens in the brain of a patient when he is asked to think about something specific.

P. That is good enough but you have told the patient to think. Your experiment only says that thinking occurs in the brain.

M. You are right. Nevertheless we were happy about seeing what we may call a thought. We also saw another phenomenon, namely that thought precedes action. A simple example: when a patient bends a finger this action is seen first in the brain.

P. I had the same – of course entirely unscientific – experience many times. Before I write something on paper it has to be in my brain first. And before rising from my desk I had the impulse to do it. Unless I was very concentrated on something else. Then this movement was more automatic, if I remember right. Before making this kind of experiment I think one should try introspection first.

M. You are making fun of me. Nothing seems to impress you. But I try again. That actions start in the brain, can we not see this as an hypothesis?

P. I think not. It is somehow too obvious.

M. But let me take something from ordinary life: A man is going to cross a brook on a narrow footbridge. He hesitates a bit but then he thinks that this looks rather easy. This is his hypothesis. Then he falls into the brook and his hypothesis is contradicted. How about that?

P. I do not want to use the word hypothesis here. The situation is too trivial.

M. I read about you that you once had thought a lot about a mathematical problem. And then, as you left the bus in Caen, the solution passed through your head.

P. No explicit hypothesis was involved. Only a long period of preparatory work. That such things happen is not uncommon. A hypothesis must be the result of some serious thinking.

M. Our problem is that the word hypothesis is difficult to use in communication with patients. It is too vague and can be misinterpreted. Doctors, by

the nature of their work, become bureaucrats in a way. And a bureaucracy cannot live with hypotheses.

P. May be I overrated the general usefulness of hypotheses. You are right that there are fagots and fagots. But in all kinds of serious research hypotheses are necessary. This is my last word.

M. But I still hope to satisfy you. Medicine is on the threshold of period of a very interesting research.

P. And what is that?

M. Fifty years ago it was discovered by X-ray spectroscopy that all living material contains long molecules having the form of double helices. They contain the secret of life.

P. What double helix? Explain yourself, please.

M. I do not know exactly how to describe it. The helix consists of two coupled spirals. If unwound the double helix takes the form of a ladder with steps. Each step has two parts with names that I have forgotten but the entire molecule is called DNA after chemical names that I have also forgotten. Each step has been given a name with two letters out of four fixed ones.

P. Hence there are sixteen ways of naming a step.

M. I believe you. You are a mathematician. But only four of them are used by nature and, if we disregard order, just two. If we give each step a letter DNA can be thought of as a very long word consisting of just four letters. These words differ systematically between species and a little between individuals of the same species.

P. I am amazed. Nature has a mathematical code.

M. Now comes the important part. Living matter consists of cells. When cells split into two, the DNA of the original cell halves itself into two simple spirals each of which is able to reconstruct the missing half from material available to it. Don't ask me how. The result is that DNA passes unchanged to new cells.

P. When Laplace worked with planetary movements he concluded that God is a mathematician. It seems that his hypothesis has now received an independent confirmation.

M. I am pleased to hear that you can joke a bit. By the way, does God exist on the other side?

P. May be. At least there are rumours. But let us return to your subject. A code is all right, but what is it supposed to be good for?

M. DNA is supposed to regulate the growth, life and death of protein in living matter.

P. So, DNA is the blueprint of life and death of all that lives. Is this the great hypothesis of biology and with it medicine?

M. Yes, or rather, was. Quite recently one has been able to read the DNA of man and divide it into tens of thousands of groups called genes which can be tied to well defined kinds of proteins.

P. How can you say that a catalogue verifies the great hypothesis? This is an illusion. One must also know the details of the action of DNA, not only a catalogue.

M. But there are genes tied to definite illnesses. It may be possible to cure them by some kind of genetic engineering.

P. My question remains. DNA is a wonderful code but you have to know in what sense it guides the birth, life and death of an individual. A multitude of questions come to mind. I believe that organic material can interact in enormously different ways.

M. There is hope of a solution, and a lot of money goes into molecular biology.

P. Only a very limited number of hypotheses seem to be essential to physics. But so far molecular biology seems to me not to be in the same situation. But my belief is that a limited number of well chosen hypotheses are always able to put some order into at least some parts of a recalcitrant material.

M. Maybe it is this belief that makes molecular biologists hopeful even when they have little to say.

P. Perhaps. But please remember that it is not possible to have too many hypotheses at the same time. That is too much for the human brain. We can drown in hypotheses.

M. You should perhaps address yourself to molecular biologists. Since my daily work does not stand hypotheses I have nothing to add. But what you say seems all right. We shall see.

P. Yes, I now have a got a lot to think about. It will be interesting to follow what happens even in the somewhat reduced way available to me over on the other side. I have now material for a second edition of my book, but unfortunately I cannot write it. I envy you your living conditions. Thanks and goodbye.

(*P. Becomes silent for a while. Then his shape dissolves and M. is left alone with his computer.*)

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THE SOUL OF SCIENCE I

5 Science and Common Sense

The characters of this dialogue are Simplicio[4] *(C.), representing common sense, and Lady Scientia, the guardian spirit of science. Their conversation takes place in a somewhere, entirely free of earthly appointments.*

C. I do not know how I came here or what I am supposed to do. You, dear Madam, may perhaps know something.

S. I do indeed. For a start we might perhaps introduce ourselves. My name is Scientia and I love, protect and represent science.

C. I am Simplicio. My friends think that I am the embodiment of Common Sense. I can say without bragging that I solved many a dispute with my common sense.

S. Do you happen to be the Simplicio who appears in Galilei's famous dialogues?

C. Yes, that's me.

S. I believe that I remember that Galilei, masked as Mr. Salvati, had great trouble convincing you that Aristotle's thesis that heavy bodies fall faster than light ones leads to contradictions. But is that right? Don't stones fall faster than leaves?

C. Do not test me, please. The reason for the different velocities is that stones and leaves have different air resistances. Galilei himself reduced the problem to heavy bodies of the same density and form.

S. Sorry, but how were you convinced? It is a long time since I read Galilei's book and my memory of it is a bit vague.

C. I was convinced in several steps. How it happened is a very interesting story.

S. Tell it to me, please!

C. Salvati convinced me by two thought experiments. First he assumed with Aristotle that the velocity of a falling body increases with the weight. Then he considered a small stone on top of a bigger one. At rest the small stone presses against the big stone. But this does not happen when they fall: if it

[4] Galileo Galilei was the first to formulate the law of free fall: air resistance being disregarded, all heavy bodies fall to the ground with constant acceleration. To explain this law, essentially the first example of so-called hard science, he wrote a collection of dialogues *Discourses and Demonstrations about Two New Sciences* (1638). The text argues against Aristotelian physics and the readers have to follow close reasoning and accept thought experiments. The task of one of the characters, Simplicio, is to put questions and receive answers which in the end convince him that Galilei is right.

did the smaller stone would increase the velocity of the bigger one and this does not happen. Hence a small stone does not fall faster than a big one. So far Aristotle may still be right.

S. And then?

C. Salvati suggested to put the big stone above the small one. If Aristotle were right, the small stone with its small velocity would then prevent the big stone from falling with its proper velocity. But together they are heavier than the heavy stone and hence, according to Aristotle, would fall faster than the big stone alone. It became clear to me that the view of Aristotle leads to contradictions. I gave up my trust in Aristotle but I also felt a bit sorry that he was not right. Later, when Galilei dropped a small and a large ball from the leaning tower and both hit the ground simultaneously, I was not surprised. I already knew that Aristotle was wrong.

S. Aristotelian thought was once considered to be common sense. You should not feel sorry that he was wrong. Common sense is a gift to man from birth and something to be proud of.

C. Of course I am proud of it. But Galilei made me change my view of common sense. It is open to improvement by thought and especially by thought experiments through which one discovers paradoxes that have to be eliminated. The result for me is that I now represent a modernized and developed Common Sense that does not dismiss thought and thought experiments. On the contrary. After my time with Galilei I did not find it difficult to accept Newton's rules of motion such as the inertia of matter: every body remains in its state of rest or uniform movement. If it is not subject to exterior forces of course.

S. What you say contradicts common sense. Uniform movement has only been observed during very short time intervals.

C. But this does not contradict common sense. I know as well as you, Madam, that most motions are not uniform when exterior forces are involved.

S. I was only trying to joke, I believe as you do that science has to work with simplified assumptions and thought experiments.

C. Otherwise there is no order. So says my common sense.

S. We could perhaps start discussing some interesting problems, now that we have so much in common. But first let us be precise and state the conditions of our discussion. Science always advances and therefore its position changes with time. I decide to adhere to the present position of science. And you, Mr. Simplicio?

C. Common sense is of course more constant than science, yet it, too, varies. Let me say that I stay by the present position of common sense.

S. But science and common sense have differed many times also since the time that the Catholic Church was its representative on earth. How did you, Mr. Simplicio, react to the rods of relativity theory which get shorter when they

move fast and to the observation that time slows down in the same situation? It being understood that the rods could measure time.

C. I had of course great difficulty, but Galilei had prepared me. He taught me that there are many ways to understand reality and that numerical arguments have a purifying effect on all ideas that come from immediate observation. Therefore I came to see the theory of relativity (the special one to start with) as a model which put order into all the effects and properties that follow from the fact that the velocity of light in vacuum is independent of the velocity of the source. Let me also add that all these effects are too small to be immediately accessible to common sense.

S. You speak in a proper scientific manner, Mr. Simplicio. Bur how do you separate common sense and science?

C. I make a clear difference. Common sense does not create science. Its purpose is to observe science from the outside and at the same time understand it. Perhaps not all but the most essential and important parts.

S. But this means that I would be subordinate to your judgment, Mr. Simplicio. I must say that you have come a long way from the minor part you played in Galilei's dialogues.

C. Please do not do not excite yourself, dear Madam. Common sense is more or less shared by everybody. Just as you, dear Madam, is responsible for science, I am responsible for the right use of common sense in all weather. I believe that we could agree on the proper use and range of common sense. Without enmity and prestige and in all harmony.

S. I think that the picture that you paint is too idealistic, but I agree that we ought to be able to meet in civilized fashion as becomes decent people. But now, common sense has met worse ordeals than special relativity. I am thinking of general relativity and quantum mechanics. How did you fare with them?

C. The theory of general relativity raises more questions than it answers. For me it is a clever construction that can explain many phenomena that would be unexplained otherwise. If you excuse me I have found that this theory is not a fruitful ground for common sense. To me it is a beautiful mathematical construction whose value lies in the predictions that it makes.

S. It was nice to hear that at least some part of science remains free from the judgments of common sense. To me general relativity is the foundation of cosmology. Without it we can not say anything sensible about the universe.

C. You forget, dear Madam, that quantum mechanics is an indispensable part of cosmology.

S. Sorry about that, I went too fast. But before we continue it would be interesting to know how common sense reacted to quantum mechanics.

C. As I told you earlier, I learned from Galilei not to be afraid of abstract thinking. I accepted the foundations of quantum mechanics but I hesitated

in the face of the difficulties that arise from the quantization of classical mechanics. But I think that a new generation of physicists have grown up with quantum mechanics are no longer worried by these problems. Certain parts of reality are now seen directly as quantum mechanical phenomena without a passage from classical mechanics. Permit me to say that this does not contradict common sense.

S. Look here, Simplicio, you talk like one who really knows what you are talking about. What you do not say is that your acquaintance with quantum theory is very superficial. You did not understand the mathematics of quantum mechanics and you did not yourself write a single article in the field. In spite of that you sound like a real expert. You got your views from reading popular reports. Such reports are only rarely written by people who understand what they are saying.

C. Madam! You are absolutely right of course! But please realize that if you force me to talk about science I must use the same phrases as the experts when they try to express things in a common sense language. But if you excuse me, my experience with Galilei has given me a general idea of what science is and I have found that this general idea is useful when trying to get some notion of more modern parts of science.

S. Please excuse my little explosion. It is clear that we sometimes use the same expressions from science and this obscures the fact that I have a deeper understanding of science than you ever can achieve. So when I say that the combination of quantum mechanics and general relativity has made possible a deeper understanding of the universe, in particular the theory of the Big Bang, I speak with some authority.

C. I agree that the Big Bang is a striking and audacious theory. But why the word Bang? No one heard this Bang and it is questionable that air was present to make it possible to hear.

S. Dear Simplicio, you must understand that the word Big Bang is a joke and that this joke has given the theory its name, not its content. Otherwise I agree with you that Big Bang is just a theory.

C. We should perhaps not bypass the new biology. I mean the discovery of the genetic code.

S. I find it amusing that Mendel's simple combinatorics should be followed by another one albeit not so simple. But I doubt the expectations that the genetic code alone is going to create order among all proteins and the way they are created and live in the human body.

C. Here you agree with common sense. We agree entirely.

S. This is not the first time that the range of a scientific discovery has been overestimated. I am thinking of what once was written about Newton's *Principia*.

C. Yes, I remember that. Many of these comments challenged common sense although Principia in itself was sufficiently sensational.

S. I want also to say something about the appearance of computers in science. The discovery and theory of semi-conductors was a very nice thing. The applications have meant a revolution in many fields, for instance all kinds of bookkeeping and numerical meteorology and other areas where theory can be subject to numerical computation. But those who talk about computers as a scientific progress do not realize what science is. It is really an activity...

C. (*breaks in*) You need not lecture me. Common sense can itself distinguish between science and what looks like science.

S. Excuse me, but this you cannot do without the assistance of science and, in many cases, time itself.

C. I am sorry that I overstepped my bounds. I hope you forgive me.

S. My dear Simplicio, I want to point out a serious, recent turn in the development of science which concerns both of us.

C. I am sorry that I do not know what you are referring to.

S. It is a phenomenon that I want to call the industrialization of science.

C. Please explain it to me.

S. In the last forty or even fifty years science in the sense of natural science has received more and more support from industry and the state. Both these donors, since they control the money, give rise to a new kind of scientist driven by a wish to be useful to state and industry and by the desire for money. Much of this is of course inevitable when the many applications of science are carried out. Perhaps science has been too successful for its own good. An outward sign is the fact that the number of scientists and scientific journals seem to have grown exponentially for some time. The journals that carry short accounts of scientific results and were once read for pleasure have grown out of proportion as have their prices. All this growth can be studied in the long catalogues free from quality control which are available to us by present information technology. All this makes my situation very difficult. An unlimited growth is not something that I or anybody else want to attend to. What once was called science has become a large market with all the signs of a market: a fight for money and the attention of the public. And attention itself attracts attention. There are trend analysts for science and the popularization of science. Earlier a scientific article used to have one author, now as a rule there are several of them. Scientific merit stands the risk of being collective.

C. I think it is only natural that science is industrialized because the world has been industrialized. Everything is now performed on a bigger scale than before. You used to admire scientists performing great feats of thinking in a simple world. This is a thing of the past.

S. My dear Simplicio now you are doing some phenomenological thinking. What you say is that things are as they are because of the way they are. But

you are right that I do perhaps idealize the past. Please realize that quality in science is to me something that is almost independent of time. And I am a specialist in distinguishing quality. It is true that indifferent science has always been produced, at least after the eighteenth century. But now it is produced at fast rate.

C. Please give me some examples.

S. Earlier, biologists were peacefully studying animals and plants. Now after the first ecological scare they become ecologists and get new money for something they did not quite knew how to handle. But they write. And the scare that all oceans will rise to dangerous levels now keeps hordes of meteorologists busy.

C. Now that you have mentioned it, I realize I have noticed the same tendency. After reading the first page and the summary of a scientific paper, I often think that it is time to stop.

S. My dear Simplicio, you are now again masquerading as a scientist. Just reading is not enough to evaluate a paper. As an amateur you do not have the necessary insight to do it. I have said this before.

C. I admit my faults but Galilei and present company inspires me to express myself in kind.

S. Anyway, when I read scientific material, it takes a long time before I give up. My responsibility as a guardian spirit is clear. You used the word scientific not long ago. As a lover and guardian of science I must control everything that goes under that name. Recently this task has become heavier and heavier to me and also given me some unpleasant feelings. Simplicio! Science has definitely a soul visible to me in some of the best work done, and I believe that you can at least feel something of it. But now I can sometimes read entire volumes of scientific journals where nothing of interest seems to come out and the soul of science feels very, very distant. I have seen that the scientific method so beautifully applied by Galilei, is being applied nowadays to material that yields very little. And that some themes are being overplayed in the sense that only very small progress is achieved in every paper dealing with the theme. I do not quite know what to do, Simplicio!

C. Then, how should I know? The word science is perhaps not well defined. The definition lies in the user's mouth. The general public...

S. Let us leave the general public to itself. Otherwise we will never be able to end our exchange of views.

C. Long ago the situation was very simple. Science was an activity exclusive to academies and universities. But then there were no applications to speak of. Now applied science floods the market. This branch has a tendency to correct itself since its failures are costly or soon forgotten. One could say that it purifies itself. If you want some relief in your work you could perhaps leave applied science to me. I want to become the guardian spirit of applied science. It will be a suitable occupation for common sense.

S. A suitable occupation! You forget your historical mission! Common sense is free and independent from all and everything. As a guardian of applied science you tarnish your historical mission! What the world needs is common sense, not applied science. If you do not understand this, woe is to mankind.

C. I am sorry, you are right. I really regret my heretical ideas.

S. Now, when you said 'purifies itself' it made me think that science like all intellectual activity is subject to the same process. The next generation is always ready to criticise. Almost every established theory or belief is modified with time and some have a short life span. Science that is not fit for life dies on the shelves of libraries or in old hard disks. I feel I am getting some strength from this thought. I am now resolved to continue my work with everything called science, although part of my role is no longer that of a sweet guardian angel. I mean that I will read and evaluate everything as before but I will not always feel protective and nice. I will permit myself to hope that some things that I read will be forgotten as soon as possible. This feeling will make my life easier. It makes me optimistic for the future. And with better search machines for the net I could still fulfill my historical mission. I have made my decision and I feel relieved. My work is waiting. I thank you, dear Simplicio, for a fruitful conversation. Farewell.

C. It is risky to say farewell to common sense!

S. No cheap jokes please! Think of your reputation. Farewell!

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THE SOUL OF SCIENCE II

6 An Interview with Lady Scientia

An interview at the premises of the Royal Society, London, gives Lady Scientia (S.), the guardian spirit of science, an opportunity to state her views on science and what she sees as its soul. The reporter, Kay Cary (C.), is specialized in biology and medicine

C. When did you arrive in London?

S. I think we should switch to some important subject. Science for instance.

C. What is your opinion of British science?

S. We had better start with a definition of what science is.

C. Yes, please give me a definition.

S. Science is its own purpose and the purest expression of man's theoretical drive. Science means correct reasoning and methods and results not immediately accessible to common sense. My definition is not too precise but it serves to separate science from phenomenological knowledge. On the other hand it has to be specified to identify scientific elements of human activities like industry and agriculture and so on. But I believe that my definition can serve us for the moment.

C. What do you mean by 'the theoretical drive of man'? I never heard the expression before.

S. The drive to understand the world we live in by means of theoretical constructions.

C. Some words about phenomenological knowledge? Please!

S. Research that stays on the surface and avoids theory. Common sense is an example of phenomenological knowledge.

C. Thank you. Maybe I could represent common sense.

S. I have as much common sense as you. We have to share.

C. But common sense finds it often very difficult to understand science in all detail. That is a often experienced by a journalist.

S. You are right. I believe we shall understand each other. Let me first say that what we call science can exist only under certain conditions. Writing is a prerequisite and the scientist must have an independent position. These two conditions were first satisfied at the major royal courts of antiquity, for instance those in Babylonia and Assyria some three thousand years ago. The princes were of course more interested in their power and horoscopes than in science. But life close to the courts gave the scientists both leisure and independence.

C. When were you first interested in science?

S. Just about then. Three thousand years ago.

C. That is not possible.

S. But that is what it is. Possible. You must realize that I come from the other side. Now and then I assume a human shape and visit the world of humans. Nowadays I restrict myself mostly to academies. This interview, by the way, is a mistake by the administration. Normally I never meet the press. I am here to investigate the minds of certain interesting scientists but I have also other methods of finding out the truth. But now when things are as they are, let us continue.

C. (*Shows signs of uneasiness and panic but calms down after a while. Lady Scientia does not seem dangerous.*) Yes, well, let us do that.

S. First you must understand that, coming from the other side, I have no difficulty in reading scientific material. I make some excursions into the reality where you live in order to complete my impressions. Let me tell you a bit of my life as a guardian. My present life began when those in command gave me the task to guard science and investigate its conditions. That was about three thousand five hundred years ago. That my name is the Latin Scientia is no contradiction. It is simply a suitable name taken when Latin began to appear as a language of science.

C. Who gave you the task?

S. You ask too much.

C. Please excuse me. But I think that three thousand years cannot be enough. Were not the Egyptian kingdoms older than that and the Egyptian mysteries still more enigmatic than the Babylonian and Assyrian ones?

S. You have misunderstood me. I repeat that science means correct method and results not seen immediately by common sense. You must not, as does the public, confound religion and mysteries with science. These activities can sometimes use a kind of prescience but they have nothing to do with science. Perhaps one can say at most that Egyptian archaeology is a kind of science.

C. But the pyramids! Were they not built by science?

S. No, to draw a square in the sand and compute a slope is not science. Perhaps applied science and this is not my field.

C. Well, what shall we then speak about?

S. Continue the interview!

C. Give me an example of scientific achievement.

S. A Greek astronomer's giddying thought that the earth could be a ball that gets its light from another ball of fire, the sun.

C. Who was he?

S. The thought originated with an unknown astronomer and met with resistance but the arguments in favor became more and more convincing. This development fills me with delight.

C. Describe your delight to me, please!

S. Like everybody's delight. My feeling is personal. I want to keep it to myself.

C. Give me another example of science, please.

S. Euclidean geometry.

C. Why is this science? It is awfully old and taught in the schools to bored children.

S. Because the method of starting from axioms is spotless, because the results are interesting, because together they form a harmonious unity.

C. You forgot the bit about common sense.

S. Many geometrical results are intuitively true and therefore acceptable to common sense, but common sense uses only conviction, not arguments and proofs. Many results leave common sense cold, for instance that the axiom of parallels means that the sum of the angles of a triangle is half a turn.

C. This sounds terribly complicated. Do all scientific results have to be incomprehensible?

S. Much of it is now common knowledge, for instance that the earth is a ball. But the insight and the proof of this fact was science.

C. But all the philosophers, Plato, Socrates and all the others. Did they not write science?

S. They wrote philosophy. Philosophy requires neither strict logic nor results accessible to common sense. Philosophy for philosophers is one thing, philosophy for the general public has to be entertaining and offer some surprises.

C. Let me go back a bit to the royal courts. What about them?

S. I should perhaps make an exception for the ancient Greek republic. But Archimedes, for instance, lived close to the tyrant of Syracuse. The scientists of the old world had free contact with the political power; without this they could not have devoted themselves to free science.

C. I remember this Archimedes. Wasn't there something with a fixed point?

S. Yes, in a mythical statement. Archimedes wrote about astronomy, mechanics and large numbers. He proved that the area of the sphere is four times that of any of its great circles and other similar results.

C. Unknown to me. Can't we leave antiquity?

S. Not quite. The road-building and military art of the Romans was brilliant but not science. But when I think of the seventeenth century it is with considerable delight.

C. Why?

S. That was the heroic century of science. Galilei, Kepler, Newton, Leibniz.

C. Does their work really satisfy your criteria for science?

S. Almost all of it. Galilei's laws for falling bodies are logically perfect, not immediately accessible to common sense and verified by experiment. And then

the great breakthrough: gravitation and mathematical analysis. You know of course that I am thinking of Newton and Leibniz.

C. Why do you always insist on the part about common sense?

S. Because I want to separate science from common sense.

C. And intimidate me and the greater part of humanity!

S. Try to understand some serious science and you will realize that common sense is not always a sufficient tool.

C. Maybe, I did not try much. In the seventeenth century you forgot Descartes and Pascal!

S. They would fit if we could disregard Descartes's philosophy and Pascal's religion.

C. You are too strict. Must your science always be perfect?

S. The word perfect does not exist in my vocabulary. All science is provisional and temporal.

C. And the scientists?

S. They are human and in general far from perfect. Newton made a serious study of the topography of Hell.

C. But relativity theory! Newton was wrong if I remember right.

S. I just said that science is provisional and temporal.

C. Excuse me! Could we not leave science for a while? Please describe again what you feel when you are delighted about something scientific.

S. You mean my feelings of delight in the seventeenth century.

C. Precisely!

S. I was of course not delighted throughout the entire century, only when I thought about the many important results brought about by the new possibilities opened up by the scientific method.

C. But isn't it an oxymoron that something as dry and involved as Newton's theory of motion and gravitation could cause delight?

S. You forget whom you are interviewing. My name is Scientia, I am the guardian angel of science, to use religious terminology.

C. I beg your pardon. But if we leave the seventeenth century, I come to think of Darwin and *The Origin of Species*. Any feelings about him?

S. Of course I know about him. My problem is to decide if what he did was science. There are many useful and necessary activities that are not science.

C. Yes, but really, Madam, I just happen to know that Darwin is our greatest scientist here in England.

S. I understand that I go against common usage of the word when I say that Darwin was not a scientist. He was first to arrive at the first sensible conclusion from the fact that there are remnants of many species on earth

which are now extinct. From my point of view he represents am elevated form of common sense, since he arrived at an inescapable conclusion. I admit that my definition of science is not perfect. But that is what I go by. In my mind a large number of giants of erudition , for instance Linnaeus and all great historians share Darwin's position. It cannot be helped.

C. But dear Madam Scientia! I am shocked. All I learned comes to nothing.

S. Not to nothing, I stick to my definition of science and I ask you to respect it for the moment. By the way, now that we are in the eighteenth century, I must remark that the royal courts have been replaced by academies and universities as places for scientists. And in a new development the big foundations and the state have replaced the prince.

C. How?

S. They pay without interfering.

C. Oh yes!

S. In your 'Oh yes' I heard both irony and rudeness. Such things are not in order when you speak to me.

C. Sorry, I beg your pardon.

S. I cannot pass over my favorite century, the nineteenth century. Small universities, little money and good science that laid the foundations for all future progress.

C. Please give me an example!

S. For instance chemistry. I am thinking of the discovery of new elements and the construction of a list of all elements, valid in the entire universe and explained by the theory of atoms. It was the basis of the present chemical age with new materials everywhere. And physics: the discovery of electricity and the theory of electricity and magnetism which foresaw the existence of electromagnetic waves used in all global information systems.

C. Do you mean radio or television?

S. Both. It is the same theory. I do not have time to explain. For me it is something tremendous that humans by experiment and thinking have understood processes which are valid in the entire universe.

C. I have made a note of that.

S. We must try to have a friendly, respectful encounter. The present situation makes it impossible for me to explain complicated things in a few sentences.

C. I am sorry. Can't we leave the nineteenth century?

S. Very well. The first part of the twentieth century was just as good. From my point of view of course.

C. Why?

S. For instance Einstein's relativity theory and quantum mechanics.

C. Merciful God.

S. What do you mean?

C. It was a personal lament. You mentioned two things that are notoriously difficult to understand and explain and that go against common sense.

S. If you excuse me, they are no problem for me.

C. Please speak about everything that happened after the war with television and the atom bomb and so on.

S. What you speak about has its origin in the science of the preceding century and a bit into this one but is not in itself science.

C. It seems that nothing that I know or understand is science.

S. That's about right. And it isn't your fault.

C. Did science end after the war?

S. No, but the funny thing is that I don't have more to worry about now than earlier in spite of what is said to be accelerated progress.

C. How is this possible?

S. I do not know but it is so.

C. But when I think about the situation in the West, in the USA and England, where there are many new universities, discoveries arrive almost daily and there is an extensive press coverage of science. I think that this means more science.

S. I keep track of all important progress in science and the field has not increased qualitatively.

C. Can this be really true?

S. This depends on two things. Science is becoming indispensable in warfare and the results of science can be used to earn money.

C. Now you seem to have turned to a different subject, contemporary history. Not such a scientific a field, I assume.

S. You are right but as a historian I limit myself to science. I do not despise phenomenology and what is generally called science. As I said before both are indispensable in human culture but they are not science as I see it.

C. Cheers!

S. That was not entirely complimentary, I understand. To explain to you my present situation and that of science I must go back about fifty years.

C. I am waiting.

S. The prince has changed his relation to science. Everything depends on that.

C. But there are no princes in science any more.

S. I know well that the role of the prince as a prerequisite for science has been taken over by the national state, but remember that I have a long perspective. My prince is a metaphor for something whose existence is necessary for science. Everything becomes clearer if I call the national state a prince.

C. I see.

S. So, fifty years ago, just after the war, the prince realized that science had been very useful and even essential for a victory.

C. An example, please.

S. Electromagnetic theory made possible the radar equipment that conducted the bomber planes over enemy territory. Radar gave the one who first used it an advantage. Relativity and quantum mechanics showed that a large energy quantity was available in an isotope of uranium. This became the atom bomb.

C. Was there anything wrong with that?

S. The prince started organizing science to further his own purposes. In this way an ulterior motive foreign to it was imposed on science. In this way it lost its soul and was no longer science.

C. Not science! I recite your own definition: Science means correct methods and reasoning and results not immediately accessible to common sense.

S. Your forgot the first part: Science is its own purpose and the purest expression for man's theoretical drive. In the new situation science is a tool for the prince's lust for power.

C. But nuclear power?

S. An application of quantum mechanics and chemistry.

C. Well, yes.

S. The prince can act fast and sometimes in a wholesale fashion. When the Soviet Union shot a satellite from Siberia into space around the earth the prince of USA showered money over science and even the linguistics of Siberian languages got part of it.

C. Interesting. More examples?

S. The prince in one Scandinavian country has repeatedly reorganized existing universities and created new ones to further his dream: science for everybody.

C. And then science is not longer worthy of its name. I suppose.

S. Quite right. In other countries the prince has tried to make an industry out of science and in this he was helped by his country's strong industrial tradition. Perhaps I should not blame the prince for all this but he certainly is involved, whether by choice or necessity I am not able to say. This new development has meant a flood of material labeled scientific. My unlimited capacity to read, understand and evaluate a scientific text is not impaired by an increasing load, but I am more than sorry to see so many articles that represent smaller and smaller progress compared to articles published before. Besides you see an increasing number of names in the list of authors. This is happening at an increased rate in biology, for instance in your country's most prestigious journal. I am sure you know which one I mean. The same phenomenon can be seen in physics and even in mathematics. Science is becoming diluted and man's theoretical drive is being industrialized.

C. And your feeling of delight is also diluted I suppose. As a science reporter I have some insight in what you are talking about. If the prince wants to industrialize science he has willing helpers. To be a researcher is not a bad profession. Lots of free time, good working conditions and an interesting job.

S. You are right. But not all forces that make humans work give good results. A progressive devaluation of science is the last thing that I want.

C. Maybe you should call a press conference and make your thoughts public.

S. You forget that I am from the other side and that my press conference will end in absolute bedlam when the press realizes where I come from.

C. Sorry, I did not think of that. But how will the public know about your ideas about the industrialization of science? I think they are very interesting.

S. I always keep myself in the background. And I have time. Truth will always come to light.

C. I want to write an article from my notes and I expect this to be a rewarding and interesting job. It is very unusual material coming from the premises of the Royal Society.

S. Yes, yes, well, then we are done. Good bye. Please do not shake my hand, it will give you a spooky feeling. Good bye.

When she arrived at her newspaper, C. found all her notes reduced to blank paper. And from the recorder one could only hear a quiet rustle.

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THE SOUL OF SCIENCE III

7 Scientific

Two young people, Elisabeth (E.) and Peter (P.), students of medicine and sociology respectively, meet in a café and discuss the significance of their Ph.D. theses. E. has a romantic view of science and P. is more matter-of-fact. In the end P. introduces a broad definition of science: everything that employs the scientific method. But E. is not entirely convinced.

E. Hi, it has been some time. How are you these days?

P. Not so bad. I started writing a thesis.

E. About what?

P. Broadband in the Scottish Highlands.

E. But they do not have it yet.

P. My supervisor has got money to survey the need and use of the new information technology in sparsely populated areas. Half the money comes from a Scottish source, the other half from the European Union. This permits him to support two graduate students. I'm one of them.

E. But what are you going to do?

P. For a start I am sending questionnaires to all women in the highlands. The other graduate student is almost ready with his study of men's opinion of broadband technology. I shall investigate what women think of all the new services. — But look here, you were also going to write a thesis.

E. I'm doing it now. It is about a gene that could have something to do with the Alzheimer illness

P. It sounds exciting.

E. I am lying a bit. It is my supervisor who wants to find the gene although we do not know if it exists. But we have started with a genome analysis of a lot of cases. After that we shall work with rats. I have to become a specialist on a group of proteins which may be involved. The advisor tells me what to do.

P. Mine does not do that. I work by myself. First I shall describe a theoretical background. After that I deal with the answers to my questionnaire and make a comparison with the work of the other guy. I guess that I shall find that women are less interested in broadband technology than men, and I shall suggest remedies.

E. Do you have everything worked out already?

P. No, but I guess the result. Can you guess yours?

E. That we find a unique gene, which can be neutralized by simple medication. Then Alzheimer disappears from the world.

P. That sounds too god. Stop joking. Do you have something that can be called a vision?

E. My vision is that we shall perhaps succeed with the rats. After that my supervisor calls a press conference and says that we have made good progress.

P. How do you know that rats have the Alzheimer sickness?

E. When they can no longer find their way in a simple labyrinth.

P. But this can be due to other causes. In my field we specialize in finding causes.

E. We take the thing with the labyrinth as a definition. You have to start somewhere.

P. That does not sound so good.

E. But your thesis! It is just showing the obvious.

P. It is not at all obvious. We have an extensive theory.

E. Yes, I know, Durkheim and the other guys. Derrida also, I believe.

P. You do not understand the first thing about sociology.

E. Maybe. But let us not quarrel about our theses. Sometimes I ask myself if I am working in science or some industry. I could just be a small cog in a large machine.

P. Maybe you but not me. What people think about this and that is an eternal question. There are forever new circumstances. I am rather satisfied.

E. Satisfied with what?

P. I got a job that leads to a thesis and perhaps a future job.

E. Me too, but why not try some thinking of your own?

P. That is what I do all the time.

E. Do you think of yourself as a scientist? Somebody who has a big problem which is important for humanity and occupies his mind all the time?

P. I do not. But I am thinking of the problems that have to do with my thesis.

E. But do you think that it is important?

P. It is important to know how women see the new information technology. At least as important as preventing ten Alzheimers for a few months.

E. Now we are there again. Let us talk more generally. I believe that science these days is an industry and I feel that I am working in an industry. Please say something about this.

P. I'll be trying. My problem comes from some thinking committee in the European Union, not from me. But I am not part of an industry. Perhaps some service organization.

E. But that is a kind of industry. From where did the Union committee get its problem?

P. I suppose that somebody with a sense of the winds of politics found out that the Union must do something for sparsely populated areas. And the new information technology looked like a natural helper. And after that there was a policy meeting with few people and later a meeting with more people that made the decision. Many states have interests in broadband technology.

E. Very good. A perfect sociological analysis. And you are the obedient servant of the Union, on hand for every wish.

P. That has only a grain of truth in it. Whose obedient servant are you?

E. That is not so simple. Of course I am the servant of my supervisor. He leads our project and cannot work without servants as you say. But there is no one above him. He has chosen our problem, and put it on the Science Foundation market. There is no one above him I think. Perhaps he is the real scientist.

P. No, he is not independent. He is a prisoner of the gene racket. If he cannot find anything better there is always an illness and a gene. He is entirely in step with the times. Of course I can only guess. I know nothing about the field but I read the papers.

E. I think you are essentially right. The industry where I work is the gene racket. You gave it a name. On the other hand we are driven by noble motives: to cure and mitigate human suffering. But that is something one hardly ever thinks about in everyday life.

P. Do not take the word 'industry' too seriously. The discovery of DNA had to lead to an industry. Inevitably. The possibilities it opened up can only be realized on an industrial scale. Nothing remarkable about that. Sociologically speaking. And in an industry one is always like a cog. You must not have a romantic view of science.

E. Maybe I am a romantic. And this means that I think it is sad to be a cog. One does as one is told and this is the end of it. I mean a thesis.

P. But you are not only a cog. Think of ourself as a member of something bigger, a team. All the time you get to know what the others do and how everything hangs together.

E. I am still a revolutionary. I think that what I do is shabby. And you ought to think the same.

P. What I do is not shabby. It is important to know what women in sparsely populated areas think about broadband and the new information technology and how the could use it. It is important for the future of these areas.

E. Important for anything else?

P. For the Union and for everybody who sells the new technology.

E. Yes, maybe. But I'm not letting up. What we do, is it science?

P. Yes, because we use a scientific method. So it is science.

E. That makes science very comprehensive. So broad that it accepts any amount of indifferent material.

P. The word indifferent is personal. What is indifferent to one is important to another. Try to define science yourself if you can.

E. Your definition presupposes that we know what a scientific method is. You shift your definition of the concept of science to the concept of scientific method. How does one know that a method is scientific?

P. In what you said before you accepted my definition. You knew implicitly what scientific method is.

E. I admit that. But what I knew I knew from examples. Scientific method in a field is what is admitted by established people in the field. There is something of an official stamp on the word scientific.

P. I can't define the word better than you just did.

E. Good, now that we know what we are talking about we can continue.

P. How?

E. We could evaluate where we stand scientifically. You and I. I am sure that we are working on the lowest level of science. We are insignificant workers with very little knowledge of what happens higher up.

P. Speak for yourself. It may fit you but not me. I have my questionnaire and I am going to do some in-depth interviews myself. No one is over me.

E. There is someone. Your supervisor, Without him there is no Ph.D. He has to say that you are good enough.

P. I know he will.

E. No doubt... But you cannot say that what you do is great science. It started with somebody in the Union waking up the needs of sparsely populated areas. And he or she thought about the broadband racket and saw that it fitted into the political ambitions of his employer. And then he or somebody else was convinced that the matter was worth giving money to. What you do is science because you apply the scientific method to something that somebody else wants you to do. I do not claim to be better, although 'protein' perhaps sounds better to the public than 'sparsely populated areas'. Do you agree?

P. I agree with you but unlike you I like my work and think that it is important.

E. Please: I do not dislike my work. We are both in the beginning of something that could end as science. How many people do you think will read and quote your thesis?

P. I have not thought of that. Two, perhaps three, remarks in the proceedings of the Union and perhaps a line in a newspaper.

E. I think that is a realistic estimate. Science advances fast and everything done is soon obsolete. That a thesis is never quoted and lives only in lists of theses is a sign that it has contributed nothing except to the welfare of its

author. I believe both of us have great expectations to end in this class. Like over seventy percent of those who write their theses with the aid of some grant and a supervisor. The sacrifice system of science. Our theses will end in the ashes of the sacrificial fire. I think that is a realistic prognostication.

P. You exaggerate. Your big mouth has taken command over you. Please do not mind that I say so. We have hardly started working and I do not yet feel the heat of the sacrificial fire. Anyway, they give us money. Shouldn't we pay and leave?

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THE PRINCE I

8 Archimedes[5] at the Palace

In his lifetime Archimedes was a friend of two rulers of Syracuse, Hieron and his son Gelon. In this dialogue Gelon (G.) has called Archimedes (A.) to the palace. Their conversation is an early example of the somewhat uneasy coexistence of science and political power that subsists to this day.

G. Welcome Archimedes. You were a dear friend of my father's. Now that he is dead, I invite you to form a friendship with me, his son.

A. I am much honored. But I am your friend already. We met many times when you were a youngster.

G. Please excuse my formality but as a new prince I feel that it is necessary.

A. Did you read my *Sand Reckoner*? I sent it to you last summer.

G. I tried but I lost interest rather early. Numbers were given to us by our fathers and I find no purpose in inventing new ones.

A. But my purpose was to show among other things that man can invent new numbers and compute with them. This is what our fathers did. And without large numbers and people who know how to use them for counting one cannot estimate the amount of food necessary to feed a large army. Of course Syracuse has no large army but for instance Xerxes had one. Without some counting and reckoning with large numbers, he could not have moved his enormous army from Persia to Greece.

G. As you said we do not need much of this here in Syracuse. Let me change the subject a little. During my journey to Athens I spent some time talking with philosophers on the Agora. It seems that you have a high reputation there. So now when somebody refers to Syracuse as a small place in Sicily I say that my palace needs a guard of five hundred men and that the fertile

[5] Archimedes (290 B.C. – 212 B.C.) lived the greater part of his life in the Greek settlement Syracuse in Sicily and is believed to have been killed when the Romans took the city. He is universally known for some long-lived myths: his mechanical feats in the defense of Syracuse and his proverbial *Eureka, Eureka!* when during a bath he realized that a body immersed in water loses the weight of the water displaced by the body. Actually Archimedes was the most innovative mathematician and mathematical physicist of antiquity. His many works written in Greek survived and have been printed. They served as a stepping stone for the seventeenth century inventors of mechanics and infinitesimal calculus. His only popular work is *The Sand Reckoner* where he estimates of the number of grains of sand necessary to to fill a ball centered at the earth and reaching to the sun. This was possible only by giving names to a body of sufficiently large numbers. In his preface he says that he is going to disprove the metaphor 'innumerable as the sands of the sea'.

soil of Syracuse has brought forth a mathematician and philosopher known all over the Greek world. But I wonder: how did you achieve such a wide reputation? Not from *The Sand Reckoner* I suppose.

A. I was always interested in astronomy and geometry and I learned from the philosophers in Alexandria. But I soon found out that I could do better than they. I constructed a machine imitating the movements of the earth around the sun and the moon around the earth. I found out that, contrary to common opinion, it is possible to measure the area of curved surfaces. For instance that the area of a ball is the same as the area of the rounded part of a circumscribed cylinder.

G. Surprising, but to what good?

A. No good at all except for the curious mind who wants to unveil the secrets of nature.

G. In the Athens *Agora* they told me that you have said: Give me a fixed point and I will move the earth. They accuse you of belittling Hercules and even Zeus.

A. I may have said something like that in some unguarded moment. I was thinking of the lever principle in theory, not in practice.

G. Please do not explain it to me. It must be for specialists.

A. The lever principle is applied a thousand times every day at the shipyard by uneducated people. Farmers use it to break new ground.

G. Yes, but without any terrible explanation.

A. You are right that most people do not think about the lever principle. Nevertheless I want to explain it to you. Take a long stick, support it at a fixed point close to one end. When you move the larger end it is easy to move a heavy object with the smaller end. Without the lever you might not be able to move the heavy object.

G. I understand roughly but without a practical demonstration I am lost.

A. Think of a farmer with a spit prying a stone from the earth.

G. I have seen that many times but I never thought of it as the lever principle.

A. I tried to describe the lever principle to you but you can only remember what you see and cannot turn my words into an abstract principle which is a thousand many times superior to an example because it embodies in itself myriads of examples.

G. Please do not try your moral principles on me. I am not a philosopher, only a tyrant. But let me now change the subject. You have revealed and want to reveal the secrets of nature. Can you also reveal the secrets of human nature?

A. What I discovered was only a small part of nature's principles. A multitude of secrets remain. Human nature is in a way known to everybody who lives a normal life of childhood, adolescence, adult life and old age. This means

to have experienced maternal and paternal love, envy, human love, lust for power, feelings of humiliation and so on. Your expression 'secrets of human nature' is a misuse of the word 'secrets'. I guess it comes from some soothsayer.

G. I believe some of the things they say. They reveal human nature to me.

A. With disastrous results, no doubt.

G. Please do not be rude. It does not become you,

A. And please do not treat me as a child.

G. I think that we do not quite understand each other because we lead different lives. What do you make of your life now that you have attained a mature age?

A. I think, I draw figures in the sand and, when this tires me, I walk around Syracuse and meditate on the lives of others.

G. Your life seems to me a very easy one with no duties except to yourself. My day is full of duties that you know very well. All the offerings to the gods, the trials, the executions, the festivals, the receptions, the palace guard and so on. And I must keep order in the palace, receive visitors and give and receive counsel. There is no end to my duties.

A. As you say I know some of them. But there is a difference between you and me. You can only partly enjoy my privilege: To decide for myself what to do.

G. I can if I want to. I am the boss of Syracuse.

A. If you say so, your highness.

G. I hear from your exaggerated politeness that you do not believe me. I am beginning to suspect that in your philosophical outlook on life only a philosopher's life is worth living, not that of a prince.

A. I do not pass judgment about life's worth. In our time princes seem to be absolutely necessary for other people to live normal lives. I mean that princes keep order in the society, chase criminals, deter people from crime by severe punishment and so on. Princes are beneficial to their subjects. At least this is a general rule with many exceptions. May I say that princes seem to be necessary to philosophers. Where there are philosophers there are also princes and cities. But the opposite is not true.

G. Ahh, my dear Archimedes. To follow your thoughts sometimes requires hard thinking. I realize that what you say about princes does not necessarily apply to me. Nevertheless I am pleased to play such important part in the society of men.

A. My measured general statement about princes does not contradict what you just said.

G. I am pleased to hear that. I may seem happy and powerful but do you realize that my life is in danger more than yours?

A. Of course. You have power and power is always under attack. There are personal enemies, palace intrigues and then the Romans.

G. The Romans are out to conquer the world. In their world there is no place for me. I do not see myself as a Roman satrap.

A. I can understand you. Have you made any preparations for a defense?

G. Yes but my soothsayers tell me that I will lead a happy life. Military things do not interest me much.

A. If the Romans attack will they come by land or sea?

G. I do not know. My advisers have no opinion in that matter. Except one. He says the Romans are building a fleet.

A. I find this interesting. I often go down to the shipyard to see the workings of the cranes and other machines used to move heavy things.

G. Can you help to build stronger fortifications? We shall perhaps need them. I can give you command over a thousand soldiers.

A. Maybe we need stronger fortifications. But I think I may also improve the old catapult at the shipyard. It is very primitive and has not been used for years.

G. Very well, I give you the task.

A. But if I do not accept it?

G. I am the prince. Nobody in Syracuse contradicts me.

A. Yes, your highness. I will do as you want but you must understand that I do not have the military skill to command a thousand men.

G. I believe your other skills are sufficient. You have a commanding presence.

A. But I am afraid that it is not good enough for a thousand soldiers. Soldiers are useless for what I am to do . I shall need carpenters, smiths and rope-makers.

G. I will give you what you want.

A. The Romans are not known for clemency. What do you think they will do if they take the city?

G. I am not a sufficient prize to be paraded on the Forum Romanum. I believe they will kill me and some uncouth Roman satrap will live in my beautiful palace. Since the Romans have no use for mathematics and philosophy they will kill you, too.

A. I fear you are right. We will both die. But in the meantime let me think about the catapult and other things in the harbor.

G. Very well. The audience is at an end because my duties await me. I wish both of us good luck. We shall need it.

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THE PRINCE II

9 A Dream

The relation of science to political power is further illustrated in a dream that the science reporter Kay Cary had after her meeting with Lady Scientia. It is recorded in the following dialogue between Ms. Cary (C.) and the prince (P.) who appears to her vaguely dressed in regalia.

P. I am the prince. Who are you?

C. I am Kay Cary and I am a journalist.

P. Then you are the one who talked to Lady Scientia! We two have common interests or rather some points of contention. To avoid an unnecessary discussion I inform you now that I am also from the other side and that I represent the experiences of political power through the ages. I am the essence of political power, if you please. You have to be courteous and respect me as a prince.

C. Of course.

P. I am sure that Scientia gave you a lesson about her favorite subject, the origin of science. According to her, the practitioners of science are always looking for a safe haven and free maintenance. They share these traits with other fortune hunters, soothsayers, artists, astrologers, inventors and historians, just to give you a few examples. What they all want they generally find close to the prince. This circumstance can be summed up very briefly: the attraction of power.

C. That is about what she said. I thought it very interesting to hear her description of the growth of science. Now I am interested to hear your opinion. I was amazed when she said the culture of Old Egypt did not have much science. What is your opinion?

P. It was not a sinecure to be Pharaoh. Too much to do with religion and one's own passing away and funeral and so on. For me it is not easy to say what is science and what is not. I talked to Scientia about the subject but unlike her I can only see the subject from the outside. I had a lot of builders and sculptors and hordes of priests. Some of them wrote history. So what do I know? My consuming interests were to conduct war and improve weapons.

C. Horrid!

F. And extend the might of my people!

C. Yes, Your Highness. But the Babylonians had science, didn't they.

F. The old kingdom or the new kingdom?

C. The new.

P. Not uninteresting. I visited some astronomers and saw their long calculations. But I was more amused by bards and soothsayers. My big interest was better arrows to be used against lions.

C. Lady Scientia admired Archimedes.

P. Yes, I hired him for some time. Mostly he went around thinking but he did not forget his meals. He was a bit of a bore but there was something about him. As a prince one must be able to judge people.

C. Did he not help in the defense of Syracuse?

P. Not much that I saw. I believe that most of it is mythical.

C. Am I really talking to Pharaoh and Babylonian kings? I am beginning to feel dizzy.

P. May I remind you what Scientia meant when talking about me. You must realize that you are speaking to an abstract concept, the notion of political power personified in me, the prince. Abstract concepts are very important in every discussion. To have concepts and use them separates man from animals.

C. (*confused*) Sure, it separates man from animals.

P. (*soothing*) That I am a concept need not concern us much now. Let us just continue. After all, you are a journalist.

C. (*recovers herself*) Yes, I am a journalist. Sorry about the interruption.

P. So, I continue. Warring is not all I do. As a prince I am responsible for the welfare of my people.

C. I have heard that before. In politics...

P. No irony, please! Remember, not once more!

C. I promise. In antiquity didn't the philosophers criticize the power of princes?

P. You are wrong. The philosophers depended on me and did not dare to criticize me very openly. They devoted themselves mostly to the human condition from an abstract and religious standpoint. That is why they can be understood long after they are dead.

C. How can you know this when war was such an absorbing occupation of yours?

P. I was not at war all the time. As young man I took part in some academies. Plato's for instance,

C. What did you learn?

P. I only got a general impression. No details. That is the way it is when a prince studies.

C. It must have been interesting for you to read Machiavelli's book *The Prince*.

P. I leafed through it but nothing was new to me. Others may find this book interesting but to us professionals it contained nothing new.

C. Listen to that!

P. Remember that I always mean what I say!

C. According to Mrs. Scentia real science started with Galilei.

P. I know her views. They are not mine. This Galilei had dealings with the Pope, not me. My scientific favorite from that time was Leonardo da Vinci. What drawings! I was very surprised to see how many things a corpse can contain. Once I wanted him to paint my entire court. But I hesitated. Scientists are risky company and I did not want to risk trouble with portraits that did not suit some of my beauties.

C. His picture *The Last Supper* became very famous.

P. Only afterwards. As I recall, the Pope was not pleased.

C. But now the seventeenth century. This Descartes.

P. A fine courtier and entertaining, too.

C. Isaac Newton.

P. There was much talk about him but I never understood why. That things fall I consider evident. Anyway, I had to care for him when he was famous. A simple pension was out of the question so I made him director of the Mint.

C. The great writers. Shakespeare.

P. Not at my court. I heard that these writers were discussed in my absence. But we must go on. Ask me something about the eighteenth century.

C. At about that time universities became important.

P. Maybe, but a very small post in my budget.

C. The French Encyclopedia became very important for science.

P. That book was a catastrophe for me. It incited the French revolution.

C. Do you still remember how it was to put your head under the guillotine?

P. Of course I do, but as an abstract concept one does not die so easily. Political power changes owners. For a time.

C. And how did that feel?

P. Natural. I remember that the conduct of wars changed. The Prussians started using breech-loaders. It led to a lot of shooting. Deafening.

C. War is not everything! What about the new way to travel?

P. I inaugurated many railways. The trains were shaky but they meant progress.

C. How about the rising tide of industrialism?

P. Surely I noticed. And the terrible anarchists.

C. But did you notice any science? I am trying to keep to our subject.

P. Science nested at the universities without troubling the prince. Except that I was given many honorary degrees. My religious duties were no longer so numerous and I could devote myself to my power and the welfare of my

people. As Bismarck did at that time. — But look here, Ms. Cary, to get me to notice science, we have to pass to the Second World War.

C. Let us do that. What did you do?

P. I assumed so many different incarnations that it will take years to answer this question. Instead, let me be brief. Helped by this incomprehensible Einstein, another physicist discovered that some kind of uranium could split into two parts plus a lot of energy. This meant a super-weapon, born in a simple laboratory through quiet experimenting. Suddenly I had to revise my view of science. In all my incarnations. In one incarnation I got the weapon formula and wanted to keep it secret, as another one I wanted the formula and got it in spite of my adversary. The bomb became highest priority and scientists took part on all levels straight up in my own office. After the bomb was used twice, it became a scare that meant a lot of money spent for defense and new rockets. Perhaps I shall not burden you with all the details. As one incarnation I sent up a rocket circling around the earth and as another incarnation I answered by putting a man on the moon. In his place I now think that that was a costly mistake. I got nothing out of it expect paying through the nose to go to other places in the universe.

C. You sound rather cynical.

P. I am the prince.

C. Your life with science after the war. How was that?

P. Manifold. Several things became clear to me through my initiatives.

C. What initiatives?

P. I tried to have conferences for politicians and scientists. A complete failure. The two groups did not understand each other at all. I also realized that the scientists fight each other. But I had to pay more and more and create a foundation for science supposed to revise science periodically and to give grants. It is now so big and influential that the chairman is one of my incarnations. A prince of science.

C. How did you react to the two gifts of science, television and computers?

P. I took them as they came. Politics remains the same in our now democratic world. It meant that political power was divided and as a consequence there are new incarnations for me. Some interesting ones also.

C. A many-headed prince.

P. That is right.

C. Did you have some political advantage from science?

P. It adds to the prestige of the state and gives me something to praise and take credit for and brag about abroad. Indispensable for political power these days.

C. What is your most recent interest in science?

P. To fight it off. Scientists are very inventive, they always created new specialities and they always ask for more money. And they are masters of getting public opinion on their side.

C. Did you notice what Scientia calls the industrialization of science?

P. No. What is that?

C. The industrialization is the proliferation of scientific articles with a diminished scientific value. She suspects that too much material is written with the sole purpose of promotion. The fact that more and more names appear under the headings of scientific articles points in the same direction. As you know there is no promotion in science without publication.

P. That is not what my scientific adviser says to me. But it somehow fits with my impression although I did not put it in words. Ms. Cary! You just put an idea into my head. Industrialization and rationalization go together. I have a new weapon. A healthy reorganization is in order! Science has grown like an amoeba with no purpose! I will get my staff to invent and polish phrases like that and I will be able to reduce the scientific budget to a reasonable size! Public opinion and parliament will be with me! Ms Cary! Please excuse me, I have to leave you. Important work lies ahead. Farewell.

The prince fades away, ms. Cary wakes up and does not quite remember where she is.

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COMMUNICATION I

10 The Two Cultures

The fields of mathematics, physics and technology are considered useful to society but few students are attracted to them. The educator Frederick Forsyte with a formative background in political science and literature has seen the cause of this situation: the teaching of science does not employ the best methods available. His public campaign with this theme has attracted a lot of publicity but also some angry rejoinders.

In the dialogue below Frederick Forsyte (F.) confronts the teaching he criticizes. His science teacher for the occasion is Nomen Nescio (N.)

F. Welcome Mr. Nescio, I really want to know more about science, in particular what is called hard science, that attracts so few young students. I have a background in political science and a bit in literature and this may explain my curiosity. Let us start by using first names. I am Frederick.

N. I am Nomen. I feel a bit weighed down by my task but I will do my best. What shall we start with? Do you have a favourite theme?

F. Not really, only white spots. Maybe you could explain relativity theory to me.

N. Let me first explain the classical addition of velocities. Consider a person walking in the corridor of a fast train and assume that he is walking in the direction of the train. Suppose that his velocity is five kilometers an hour and that the train has the velocity of 140 kilometers an hour. In this situation an observer on the ground will observe that the person in the train moves with the velocity 145 kilometers an hour in the direction of the train. On the contrary, if the person was walking in the opposite...

F. But how can the observer on the ground really see the person in the corridor and much less observe his speed? Everything goes so fast that he has no time to think and no time at all to measure the velocity.

N. You are right, it was a stupid thought experiment. Maybe we could instead think of a person walking on a moving band in an airport. Then the observed velocity is his own velocity added to or subtracted from that of the band.

F. Added. You must mean increases and decreases.

N. Added means that if one of the velocities is a meters per second and the other b, also meters per second, then the total velocity relative to the ground is $a + b$ meters per second.

F. Formulas do not go with me. Please take figures instead!

N. If the band moves with 2 meters per second and the walker moves with the same velocity with the band, the velocity of the walker, viewed from the ground, or the floor in this case, is 4 meters per second. But if he walks against the band he does not seem to move at all.

F. Thanks. That is pretty clear. And now to relativity theory.

N. We have a long way to go.

F. But I have patience. What is the next step?

N. One hundred and fifty years ago, the physicist Fizeau found a method of measuring the velocity of light in air and water and other material. In vacuum, that is when air has been pumped away, he found the enormous velocity of 300 000 kilometers per second. The velocity is less in air and still less in water and more opaque materials. By the way, these facts explain the everyday noticeable refraction of light. But when Fizeau measured the velocity of light in running water he found the same velocity with or against the flow of water. Others after him made the same and better experiments and the result can be summed up very simply: the velocity of light is independent of that of the source.

F. How?

N. If you walk around with a flashlight in outer space and you light up an observer who can measure the velocity of your light when it arrives to him, he will always get the same figure whether you walk towards him or away from him.

F. I do not see the point of this. I never walk in outer space with a flashlight.

N. You must accept thought experiments. Without them one can't understand physics. Without thought experiments science runs dry.

F. Not my science. In my world only facts can be accepted. And I understand that also physics deals with facts in the form of real world experiments.

N. If I started telling you the details of the experiments whose conclusion is illustrated by the flashlight in outer space you would immediately start protesting. Too many facts and details.

F. I believe you.

N. I try again, also in outer space. Imagine that you are shooting pebbles from a slingshot towards an observer and that the observer can measure the velocity of the arriving pebbles. Then he would be able to notice if you moved towards him or away from him when shooting. If, for instance, you shoot standing on a rocket which moves towards the observer with a velocity of a thousand kilometers and hour, he should take care. And if the rocket went away from him, he would never see the pebbles.

F. Yes, clearly. But I find your thought experiment a bit drastic.

N. I have in mind a comparison of the pebbles and the slingshot with light and the flashlight. The results of the two experiments are entirely different. The observer finds that light always arrives with the same velocity while the pebble sometimes arrives with a large velocity and some times not at all. You must understand that the experiment with the flashlight made an entire world collapse.

F. What world? How could a thought experiment have this effect?

N. The world of commonplace observations and scientific thought about moving bodies. In our conversation the thought experiment must serve as a real one. We must be able to make hypotheses and pretend. To use make believe. Otherwise we shall get nowhere in physics.

F. Funny. In sociology make-believe is not permitted. One must have facts and theory. It is best to have both.

N. Theory is a form of make-believe, also in humanities and the social sciences.

F. That is not what we think. Theory is something that keeps together a large collection of facts.

N. But more often than not in a comprehensive and diffuse way, if you do not mind. In your fields of science, theory is mostly about interpretation. And do you not agree that theories in the humanities and the social sciences are often personal and rather imprecise? Like it is for philosophy, but good enough in spite of that.

F. Now you are talking like a wise, old humanist. But what you say is true only of certain theories. Others are very exact.

N. In physics and chemistry theory is something that has to make good numerical predictions. Within measuring error, of course. But theory is more than that. Theory is a tool for evaluating old and new observations and for thinking about coming ones. Theory is more than a summary of facts. A good theory of a phenomenon gives one a deeper insight into its nature, not only a description.

F. You are very eloquent. I can agree.

N. We could perhaps go back to relativity theory. It says that no velocity is greater than that of light in vacuum. As I said the theory started with the observation that the velocity of light is independent of the velocity of the light source. It shook am entire world.

F. What world? I asked that before but got only a vague answer.

N. Classical Newtonian mechanics. It is based on the addition of velocities.

F. Suppose, for completeness, that you give me a picture of Newtonian mechanics.

N. A picture cannot do justice to this theory. I have to start from the beginning.

F. Is that really necessary?

N. I will try to make it as simple as possible. Newton stated three laws of motion. The first one is that a body in motion, which is not subject to outer forces, moves in a straight line and with constant velocity.

F. An example, please.

N. You throw a stone.

F. It falls to the ground.

N. That depends on gravity, an outer force coming from the earth that acts on the stone. Gravity exists as a force between all matter. The more matter there is and the nearer one is, the greater force from gravity. On the surface of the sun you would not be able to stand and also burn but that is another story.

F. Your thought experiments are getting worse and worse.

N. I go back to the stone on earth. If you had thrown it in outer space at a place where the attraction from the heavenly bodies is very small you would have seen the stone move along a straight line with constant velocity.

F. But I have had enough of your thought experiments in outer space. Please stay here on earth.

N. OK. For a short time after the stone left your hand, it moved very closely to a straight line and with almost constant velocity. The effect of gravity can not be observed by the naked eye. But if you shoot against a goal with a gun you have to believe Newton. Otherwise you could not aim and hit.

F. To me Newton's law is wrong. It is true only approximatively and then only for a second. What kind of law of nature is that?

N. But you must understand that Newton's laws of motion express the inner core of his theory. All outer circumstances are peeled away.

F. But these are very important and cannot be avoided.

N. Newton's laws constitute the philosophical foundation of a theory of motion and they are verified by their predictions of planetary motion, weightlessness in satellites and millions of successful constructions of moving parts in machines.

F. That is all very good but I want you to explain Newton's *theory* to me.

N. Newton's second law says that the rate of change of momentum with time is proportional to the acting force. The third law, finally, says that to every force there is a counterforce, equal in magnitude and with an opposite direction.

F. This is impossible to understand. I hardly heard the word momentum before.

N. The momentum of a stone is the product of its mass and velocity, direction included.

F. How could you use the word without explaining it first? You do not follow current pedagogical principles. Can't you explain so that I understand?

N. To understand one must first have an example. I give you another one and regret that it takes place in outer space. Imagine a rocket with a weak but long-lived driving engine. By Newton's second law of motion it will with time increase its velocity to many times the velocity of light. But this contradicts the law that no velocity is larger than that of light in a vacuum.

F. But light and the rocket are entirely different.

N. Both are influenced by gravity. One of the first verifications of Einstein's theory was that light rays are bent by gravity when passing a big chunk of matter. The planet Venus, I believe.

F. Could we not leave light aside and occupy ourselves with Newton's theory.

N. To be able to really understand it you must first understand quite a bit of infinitesimal calculus and then yourself predict by computation a number of typical cases about things thrown and trains and cars colliding. After a while you would be able to deduce planetary motion as an exercise. How the planets move in elliptical orbits around the sun.

F. But I told you that I and mathematics do not go together. There must be a simpler way.

N. An encyclopedia addresses the public. There you can read among other things the following text about Newton's law of gravitation: '. . . a statement that any particle of matter in the universe attracts any other with a force varying directly as the product of the masses and inversely as the square of the distance between them. In symbols, the magnitude of the attractive force F is equal to G, the gravitational constant, a number, the size of which depends on the system of units. . . '

F. You told me this already in a simpler way and without formulas. I want better explanations that I can understand.

N. I did my best. I sketched a course of study. The only thing missing is a list of books you have to read.

F. But I told you that I cannot stand mathematics. And I share this predilection with 99 percent of the educated public.

N. This means that your wish cannot be fulfilled.

F. Maybe, but I am still convinced that I am right about simpler explanations. Moreover, if I remember right you said that there is something with light that says that Newton is wrong. And then I do not have to understand Newton. Besides, since his theory is wrong, it may be impossible to understand. Why is it not scrapped? I read that the ideas of Aristotle are all in the dust bin.

N. The velocity of light is immense, a hundred thousand times the respectable velocity of 300 kilometers an hour. Newton's theory is very good and for practical purposes exact for velocities that are much smaller than that of light. It is also interesting in itself and has any number of practical applications. There is no reason for you not to understand it.

F. I give up. Can't we start with relativity again?

N. It will be worse for you than Newton's theory. Classical mechanics fits very well with man's experiences with lifting and throwing. But relativity theory has no such basis in everyday life. We have no experience of extreme velocities. Finally, the mathematics that you shall need is much more advanced than for Newton's theory.

F. If what you say is true, I do not stand a chance of understanding relativity theory.

N. Now I will try a more phenomenological road. The theory says that time slows down as the velocity increases. For instance, if you embarked on a train that went around in a loop with almost the velocity of light and then came back, and we met again, I would be very old, maybe even dead, and you would look the way you are now. More: if you had been able to measure the length of a wagon on the train at the same time that I did it from the ground, your length would be much shorter.

F. You are giving me fairy-tales! Your thought experiments are getting out of hand.

N. Sorry.

F. What is it in science that makes it so hard to understand?

N. I believe that the difficulties are mostly in the exact sciences and mathematics. They are there because everyday experiences of man do not suffice as a background or paradigm for the mind. Perhaps the necessary paradigm has to be hammered in first. After that it is possible to understand.

F. I detest the word hammered in. You seem to prefer old-time teaching. As you know it is fought by the entire school leadership.

N. I mean that the study of the subjects in question requires both time and a kind of inner absorption. When the school also has to produce results with less willing pupils only a bit of rough teaching will do. That most of the stuff disappears from their heads after some time when not used is only natural.

F. I think you are wrong. There must be a way. Everybody has the same kind of brain.

N. That is true. But I repeat: everyday experience is not enough. It suffices for many things like political science and general statements about animals and vegetation but not for the exact sciences physics and chemistry. And not at all for mathematics.

F. You are wrong. Political science and sociology have many theories and most of them are difficult to understand.

N. You can say that with a certain authority. But I think that the source of the difficulties lies only in an extended terminology. The basic facts are generally accessible to the educated public. It shares its basic experiences of society and daily life with the originators of all these theories.

F. You are wrong. There are theories of state and democracy that are very difficult to understand even for me. There is a great gap between the naive reader and advanced political science.

N. Let me take Derrida or some other willful sociologist as an example. It may be difficult to understand what he means but what he says is more often than not personal interpretations based in some abstruse intellectual tradition. In

science we have constructions and notions that are supposed to be understood by anybody independently of cultural background.

F. Not everybody. You have to make an exception for me.

N. I meant everybody with enough time, interest and motivation to understand.

F. Thanks for the compliment.

N. Let us continue without personal remarks.

F. I agree.

N. If you excuse me, I have a theory about why you wish that scientists should explain their theories better to students and the public. You are led by your own experience that the social sciences and literature can be explained to the public even when originally presented with an overdose of terminology.

F. That is not my opinion.

N. Let me take the press as an example. When the press wants to explain cultural matters to its readers, the material comes from the social sciences and the humanities. My explanation is that this material can be explained to educated readers and also has an element of entertainment in it. Otherwise it could not motivate its existence in the press.

F. But the sciences, too, are written about in the press.

N. But only when the material satisfies my criterion of being understandable by educated readers. The nuclear bomb provides the background to physics, new materials to chemistry. Theory has no place.

F. But it is not right to take the press as an example. It has been watered down more and more to satisfy a decreasing ability by the readers to accept serious material.

N. The watering down has had an effect on the frequency of cultural material, not on its quality.

F. Yes, I believe you are right. I believe also that my lesson should end here with a confession. In order to survive in my bureaucratic profession I must now and then take some initiative especially when journalists are present. Therefore I once said that scientists ought to explain their results better to the public and in the schools. I think the same now but I have no illusions of being taken seriously. Most people who heard or read my message probably saw it as a pious hope if they even noticed it. That you took it seriously can perhaps be seen as professional mishap. Yours and mine.

N. After this ambiguous statement I give up my pedagogical efforts. But I hope that our conversation has disturbed a certain smugness. Whose it is I do not say. Goodbye.

F. Goodbye.

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COMMUNICATION II

11 Metaphors[6]

Below, a somewhat aggressive journalist (J.) is interviewing Boriander (B.), professor of physics, in his office.

J. You have just published a book about the inner secrets of atoms. Is it possible to explain what this book says?

B. No one knows the inner secrets of atoms. My book is only a review of the difficulties one encounters when trying to combine gravity with electromagnetism and nuclear forces. Whether these difficulties can be explained or not depends on the reader or listener.

J. But the book has received a big prize!

B. Naturally, I am happy about that!

J. The public always wants to hear more about science. Couldn't you try?

B. I don't think it is a good idea to shower the public with technical language.

J. As a member of the general public, I agree completely with you. But I think that I and my readers could need a short introduction to your kind of physics.

B. Sure. Every chemical element consists of only one kind of atom.

J. Element?

B. For instance boron and cadmium.

J. They are unknown to the public. Are there not simpler examples?

B. We can take oxygen and hydrogen. We breathe oxygen and there is hydrogen in water. Water is a chemical compound of oxygen and hydrogen.

J. Couldn't we simplify a bit and take water instead of hydrogen. Everyone knows what water is.

B. But water is not an element. As I told you it is a chemical compound of oxygen and hydrogen.

J. Sorry.

B. I repeat: every element consists of only one kind of atom. Every atom consists of a nucleus and a shell of electrons.

J. How shall I think about the nucleus? As a stone in a plum?

B. It is too concrete. Just think of it as something heavy in the center of the atom.

[6] X-rays, a Nobel prize, relativity theory and the nuclear bomb made physics a subject for the media. To convey a sense of the theoretical side of physics to the public, metaphors are a necessity.

J. Such as a stone in a plum!

B. This metaphor is too concrete!

J. All right, but this shell of electrons?

B. An electron is a very, very small particle carrying a negative electric charge.

J. But shell?

B. The word particle cannot be taken at face value. We could say that every electron turns around in an orbit around the nucleus. It is this orbit that constitutes a shell. Many electrons give many orbits that together constitute a many-layered shell.

J. Can I say that the electron turns around so fast that it can't be seen?

B. Unfortunately this is a meaningless statement. We cannot see a single electron, only its action as an electric charge. That it turns around the kernel is just a picture.

J. Shall we not go directly to the nucleus?

B. But perhaps first to the periodic table.

J. And what is that?

B. The elements can be ordered according to what is called their numbers. The number of an atom is the number of electrons it contains in electric equilibrium. The numbers of the elements go from 1 for hydrogen to around 200 for and lead and uranium.

J. This tells me nothing. Why the word periodic?

B. One can order the elements in periods with similar chemical properties.

J. What you say is getting meaningless to me.

B. It was perhaps not so smart to start with the periodic table. It is all important in chemistry but maybe not just now. So I start again. Every nucleus is built in a complicated way by gluons and quarks. The Greek word *gloios* means a sticky fluid.

J. How does it all look together? Like plums in a sauce? I am sure that you realize what dessert I am talking about.

B. Maybe you are thinking of the quarks and the gluons. This picture is too sharp. The quarks and gluons can't be seen. There are also larger units, positrons and neutrons. Your metaphor is both useless and wrong.

J. I beg your pardon.

B. You must think in a more abstract way. Metaphors do not help.

J. But metaphors help my readers. The people that I write for. What I write does not make sense without metaphors.

B. Your metaphors are harmful. The right thing to do is to imagine the nucleus as something very small that consists in a vague way of quarks and gluons.

J. I love metaphors. Couldn't I say that the nucleus is like a piece of raisin cake? I mean with the quarks and gluons.

B. No. Your desserts do not give a good idea of the nucleus and its complicated structure. Just think of the nucleus as very small and do not forget the electron shell.

J. That'll be very difficult. Perhaps a bundle of threads with the ends sticking out?

B. It is better but not needed. The atom is like a small peppercorn swarmed by very small flies.

J. Excellent! Thank you!

B. I did not mean that. I take it back. The atom is something very small consisting of quarks and gluons. That is all.

J. You forgot the shell!

B. Sorry.

J. But I try again. The atom is like a ball of white almond icing stuffed with small chocolate pieces and surrounded by curling silk paper. I think that is fine.

B. No, no please, no. If you write that you will scandalize me.

J. But without metaphors my evil chief editor will sack me.

B. That cannot be helped.

J. You are extremely heartless.

B. I understand your position but you must also understand mine. One cannot see an atom. It is only through theoretical physics and mathematics that we can say anything about them.

J. But that is not true. We can think that we see them. Atoms are small, small particles. All matter consists of atoms. The word 'small particle' is also a metaphor.

B. You are right. But if 'small particle' is all we knew about atoms and molecules we would not know more about matter than the old Greeks.

J. But they knew a lot, I think. Didn't they have atoms?

B. Perhaps. But they did not have the periodic table system, for instance.

J. And what is that?

B. I tried to start an explanation a moment ago.

J. Sorry, but I am trying to make an interview.

B. It is perhaps best that we start again with my book. It shows that the comprehensive theory, called 'theory of everything', which is is supposed to unite electromagnetism, the nuclear forces and gravitation, is logically impossible.

J. Gravitation?

B. That means attraction by masses.

J. Thank-you. What you say sounds very interesting. Theory of everything. But there is already a theory for everything. For all people and everything that happens. We have had Darwin and Einstein and Freud and people with literary theory and all the others. Frankly speaking, I believe that you are wrong. There is a theory of everything.

B. 'Theory of everything' is a facetious metaphor for a theory that combines all four known forces of nature, the electromagnetic one, the two subatomic forces called the strong and the weak force, and gravitation.

J. I can't help thinking that some people are like a force of nature.

B. That is outside our subject.

J. Sorry. But I must say that the names that you give to your forces are very bad to say the least. You have absolutely no imagination.

B. Names are inessential. The essential thing is that physicists know what they mean. Two of my forces could said to be nuclear after the nucleus. The weak and the strong nuclear force.

J. It is a little better but the public must have more than neutral names to attach their thoughts to.

B. One could say that the weak force keeps the nucleus together. The strong force protects the nucleus against strong radiation but not against very strong. Then the interior of the nucleus changes, the protons and neutrons flow together to a soup of quarks and gluons.

J. Excellent! Soup!

B. This means that very many quarks and gluons lie in disorder and tight together. As the molecules in water. We observe radiation from something that earlier was protons and now has changed to something else and must have a name. The word quark means a theoretical particle that can only be observed together with other quarks.

J. Fascinating. But can it be used for something?

B. No. We have to do with a state that can only last for a fraction of a second under the influence of extreme forces brought about by a collision.

J. So that were the two forces. And after that?

B. Electromagnetism and the nuclear forces are subject to a mathematical theory called the standard model.

J. Another neutral name saying nothing.

B. Once many physicists were responsible for the mathematical and physical parts of this model. So many that it was inconvenient to quote them all. Then the name became what it is.

J. I see. I feel uncomfortable that you mention the word mathematics. I was terrible in that subject at school.

B. It is not the first time that I hear this confession. With time one becomes insensitive to it. The task of mathematics is to give a strict frame that does not allow loose conjectures which destroy physics.

J. I am sorry about that. But what does your book say?

B. That if the standard model is extended to include also gravitation, only serious contradictions can result.

J. Why that?

B. It is explained in the book.

J. I can't take that as an answer. Say more.

B. I could say that the standard model cannot be combined with gravitation without exploding.

J. I hope it did not.

B. But it did. Under my eyes. But it was a logical explosion on paper and in my brain.

J. That cannot be understood.

B. Not verbally perhaps, but with a little imagination. It was only a personal experience.

J. And what are the consequences for the British people and for humanity?

B. None.

J. Do you think anyone would be interested?

B. No, the only thing of importance is the book where I have proved that the standard model and gravitation are incompatible.

J. Is anyone interested in that?

B. Everyone who tries to make a theory for everything.

J. You may be wrong.

B. This is an eventuality for every researcher.

J. But if what you did may be wrong, why should it be in the paper?

B. You came here. The editor who sent you tries to cover the frontier of research. Besides, if you do not write anything, nothing will appear in the paper.

J. Sorry, I take it back. I was stupid. But you must understand that you are not a very responsive person when it comes to interviews.

B. I am sorry. You could perhaps write about my hobby?

J. With pleasure. What is your hobby?

B. I share it with many. Bird-watching.

J. Yes, well I think we are ready now and I thank you very much.

The following account of this conversation appeared in the press the day after.

A discovery in physics

The walls of Professor Boriander's office are lined with books. His desk is clean except for a computer. The professor himself, in blue jeans and a green sweater, makes a youthful impression although retirement is approaching. We are going to talk about modern physics where Boriander recently made a breakthrough. He has proved that the much wanted theory of everything leads to contradictions. The professor himself, on the contrary, is not contradictory. His clear intellect illuminates our conversation when he gives me a lively description of the smaller parts of atoms, among others the enigmatic quarks, and explains that the name 'theory of everything' is a technical term which is used because so many were involved in the work that it was too much trouble to mention all of them. Therefore no one is mentioned. And it is perhaps best so now when the theory has been proved to be contradictory. Boriander describes his discovery as an explosion on paper and in the brain. But he is careful to point out that he, as all researchers, may be wrong. But we hope that time will prove him right.

J.
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COMMUNICATION III

12 Art and Science

Louise Larfeldt (L.), art professor and Patric Predient (P.), professor of chemistry, have both been engaged to appear in a popular radio program on Channel Four called Art and Science. Below they rehearse their future appearance.

L. I suggest that we start our rehearsal straight away. Call me Louise.

P. Thanks, I am simply Patric. Why did you accept to take part in the Art and Science series. It seems to me to be pure entertainment.

L. To me it is not only entertainment. Art and Science are indispensable to everybody. Without them we would not be human. Why did you accept?

P. By vanity. To be asked is a sign of appreciation which is difficult not to enjoy.

L. The same feeling bit me, too. Like you I'm only human. But in my work publicity does not hurt. When I think about our future performance I do not quite know how to start. Art and Science, painting for me and chemistry for you, seem to have nothing in common except the paint.

P. I am sure that we will have a moderator giving some kind of introduction where he says, roughly, that art and science are sisters in human culture. I have my own theory about that. I believe that the pair 'art and science' comes from the princely courts a long time ago. There art and science were both activities that were useful to the prince. Something like tokens of his princely might. For instance impressive works of art to show his good taste and science or something similar to show his spiritual powers. That is why art and science came together at a princely court. And now it is the state that adorns itself in the same way.

L. I do not believe you. Now that we live in a democracy, the prince is old hat.

P. If you excuse me, I want to insist. The state has taken over after the prince with about the same motives. The prestige that we, I mean art and science, once acquired as the finer parts of a princely culture still sticks to us. As just any chemist I would not have been invited to our program. But now I am a state official and a known scientist and also known to write in the press.

L. Your credentials are not too bad for what we are going to do.

P. Not bad at all. I admit that. They fit precisely.

L. But let us be a bit serious. In what way does the stuff we do have anything in common and in what way are we useful to each other?

P. We have not started yet. My speciality is nucleic acid. I am an organic chemist. This means that I have a vague connection with DNA, the new genetics, but only in a distant way. That is me.

L. And I am as established painter of the postmodern variety. To go with the times I began to do installations and succeeded well. Now, for a period, I am professor at distinguished art school. My students and I investigate reality and imagination in many seminar groups. My students also paint.

P. For the moment I agree with you that the paint is the only link between us. But this fact can only pass as a facetious remark in a conversation about art and science. We must in some way or other find a subject for discussion tying art and science together.

L. We could discuss conditions for research.

P. Not a stupid suggestion. Then we will be almost liberated from the attractions that made us eligible in the minds of those who run Art and Science. And we have to conceal our professional identities under a mask of experience and reason.

L. Please do not be so cynical. We do research all the time and gather a lot of experience.

P. Give me two examples.

L. We have seminars on subjects like this: 'When does a painting become a painting?' and 'When does reality ceases to be reality?'

P. But your questions do not have answers.

L. On the contrary. We ask them in connection with examples taken from our own experiences and our painting. You would be surprised to hear all the interesting arguments in such debates. Don't you have something similar?

P. No, I don't think so. Our problems are different. We must have large computer programs to master all the nucleic acids and their chemical compositions. It is for instance extremely difficult to get pure specimens. Our research deals partly with getting pure specimens, partly we worry about the interpretations of computer pictures. We do not worry about existence except for certain chemicals. I would be laughed down if I suggested a discussion with the theme *When does an experiment cease to be an experiment*?

L. But research is not only systematic work. It means more, for instance anxiety, thwarted hopes and sometimes success.

P. This is true, but where I am such things are kept strictly personal and have no chemical or human interest.

L. I think that you are wrong. Personal and individual reactions are extremely important in art. And why not in science? Personal experiences are all-important and even decisive for everybody.

P. If you do not mind I think that we have gotten nowhere with our comparisons. I mean that what we have to do during this session on Channel Four is to try to say something interesting. To make personal confessions about this and that is too common. It is better to say something about our subjects.

L. I tried but I did not hear much from you except protests.

P. Maybe, but I cannot go against the convictions that I got when working nucleic acids. But, I have an idea!

L. I can't wait.

P. We could try to discuss the part that our subjects play here in daily life in the beginning of the third millennium.

L. Agreed! I think that art is indispensable for modern man.

P. And I believe that the results of chemistry in the form of all new materials is equally indispensable. Our daily life is dominated by polymers.

L. What do you mean by that?

P. For a long time chemists have worked with long chains of molecules called polymers and this has given us plastic. The majority of things that we carry are made of plastic. Earlier the same things were made of burnt clay or iron. We live in the age of plastic. Five hundred years after us, archaeologists will baptize our time the older plastic age because pieces of plastic is all they find in their excavations. Organic material has disappeared and iron has turned to rust.

L. But plastic is neither science nor art.

P. It is not art and not science but plastic is a creation of science.

L. But I want that we shall talk about the spiritual and human side of science. And the social side, too.

P. I think that plastic has a lot to do with the social side. For instance in the third world where light plastic vessels have made life much brighter at the water wells. But I am afraid that the spiritual element that once was present in chemistry has disappeared. I mean when chemists thought about their subject in small laboratories or were happy at some discovery. All this has disappeared into the impenetrable prose cover of scientific journals.

L. That's a pity. We have tried to find something common to us both but we have not achieved much. We seem still to be where we were with the paint. Perhaps we shall need help.

P. Perhaps the moderator could do something. Let me imagine what he could say. So, when I speak now, I am the moderator and you have to answer and play your part.

L. That sounds good. Please start.

M. Tonight two distinguished scientists have agreed to come to talk about art and science, a subject of growing importance in our time where globalization and a dominating market threaten the soul of both art and science. My two guests are Louise Larfeldt, a famous painter and a professor at the Academy of the Free Arts, and Patric Predient, a world famous chemist and well known science popularizer. We welcome both of them. Perhaps I should start with

a question. How did you first get an idea of your future careers? Let me ask Louise first.

L. Already as a young girl I felt an attraction to art and music and at first did not know what I should choose. My many visits to the great European museums finally led me to painting. This became for me the only way.

M. Thank you. And Patric, if I put the same question to you?

P. Curiously enough I also imagined a future as a musician, in my case the clarinet. But then I went to the university and chemistry took over.

M. Well, you are both musicians. Did you feel anything musical in the careers that you have chosen?

P. Chemistry reminds me in a way about the music of Bach. The two have something in common, namely a careful no-nonsense texture that is sometimes broken by strokes of genius.

M. And Louise, do you feel something like that?

L. For me a good painting is a piece of frozen music. I have felt that many times wen I have done something that I really liked.

M. Isn't it a wonderful thing that you both are musicians, heart and soul! How do combine this with your daily work?

L. Not difficult. Sometimes I play ABBA when my own inspiration fails.

P. And I use to hum Rule Britannia when my work seems to go astray. It cheers me up.

M. You are both scientists in your own way. How is it to do science these days. Does your research not suffer from the new restlessness and the globalization?

L. You are absolutely right that the aesthetical sciences are strongly dependent on research. Without it we would now paint like Delacroix. I can't say that the new restlessness has entered my creative work. I try by all means to keep it away.

P. I like to go to conferences and therefore I like the new restlessness. So far.

L. You were not so bad as a moderator. Let me also try.

P. OK.

S. You represent very different branches of science. Let me ask if you are aware of each other's work?

P. I do not know about painting in a precise way, but I have eyes to see and I am not insensible. The paintings of Velasquez in El Prado once made a very strong impression on me.

L. I also use my eyes. And when I see so many things in everyday life that are made of plastic, I think that the origin of all this is modern chemistry.

M. You really seem to know about each other. Let me ask whether your professions can give you fully emotional experiences?

P. In any case some kind of emotion. I am thinking of my feelings brought about by disappointment and success. They can sometimes fill my entire personality for days.

M. I did not mean that exactly. I meant feelings brought about by a sense of the unity of art and science in our culture.

L. It is precisely such feelings that overwhelm me almost every day. Art is an infinite source of elevated feelings. Not only the unity of thought and space. And the feeling of belonging to the universe.

P. You were not bad at all as moderator, Louise, although I think you were a bit too far out in the universe. Perhaps we could finish now. I thought that our problems were more or less solved by themselves now when have had a moderator and answered some questions. I am no longer nervous about our future performance.

L. Neither am I. But I do not think that we are done. Wasn't it so that we just unawares slipped into the question of how art and science hang together and how the two fertilize each other? We assumed that this was our subject. Without thinking as one does when writing a composition at school on a prescribed subject. The name of the our theme is Art and Science. Why not see it as Art *and* Science and make something out of the *and*.

P. I am thinking and I am ready to draw some conclusions that you may have already made. In order to appear, we do not have to construct connections between art and science except for the paint. We just talk about various things as they come along. And this is what we have done. We do not even need a moderator oozing kindness and good will. Each one speaks for himself. Simple comparisons appear by themselves in such conversations. And we understand each other without any forced comparisons. We have so much in common. Everything that made us to what we are. The same language, the same upbringing and the same country. We really understand each other.

L. You speak like a patriotic sociologist but I agree with what you say. If our conversation had come straight out live on the radio we may even had been a success. By the way, what did you think of me as a moderator?

P. I thought you were excellent.

L. And I that you were brilliant. Congratulations.

P. Thanks! See you later!

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