Scientific Research and Discovery: Process, Consequences and Practice

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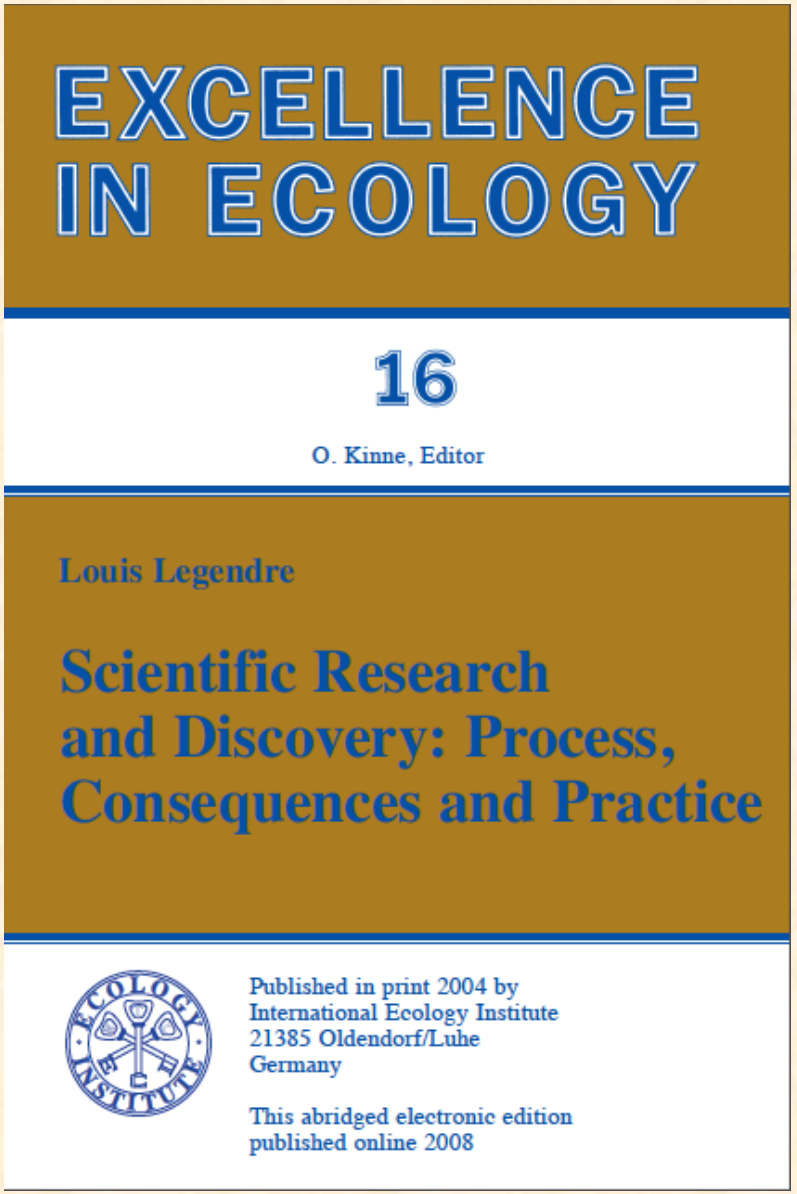
Scientific research and discovery

- Today's lecture will be largely taken from a book that I wrote in 2004: *Scientific Research and Discovery: Process, Consequences and Practice*
- In 2008, I published an electronic, abridged version of my 2004 book
  - interested students and colleagues can download it from the internet free of charge
  - http://www.int-res.com/book-series/excellence-in-ecology-books/ee16/



Scientific research and discovery

- Today, I intend to cover the following six topics

A. Scientific research and discovery

B. Scientific discoveries as Black Swans

C. Scientific creativity

D. Creative skills

E. Science and the public

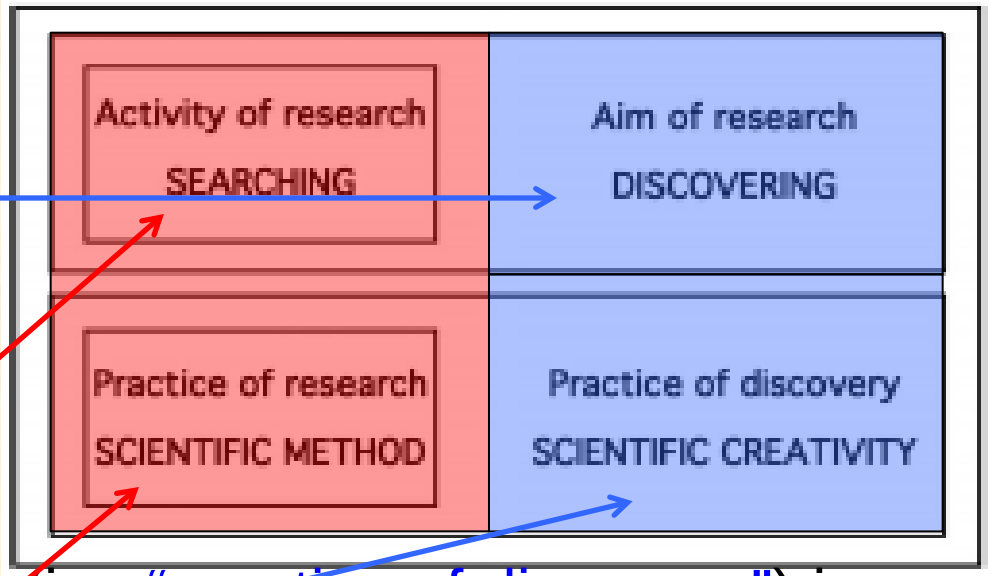
F. Scientific research as a career

- I will stop the presentation after each topic, for a discussion of the points made during the presentation

A. Scientific research and discovery

Scientific creativity

- Aim of scientific research: to make discoveries, i.e. to find something new
- few researchers have published analyses of their process of discovery → remains poorly understood
- ability of making discoveries (i.e. "practice of discovery") is called scientific creativity
- In fact, rese…ning (i.e. activity …very…ering
- training in u…arch, called scientific m…sting
- practice of …scientists suspect the existence of discovery rules when doing research



- Scientists are generally called *researchers*, not *discoverers*
- This indicates a focus on the *activities* of scientific research instead of its *aim, i.e. discovery*

Scientific creativity

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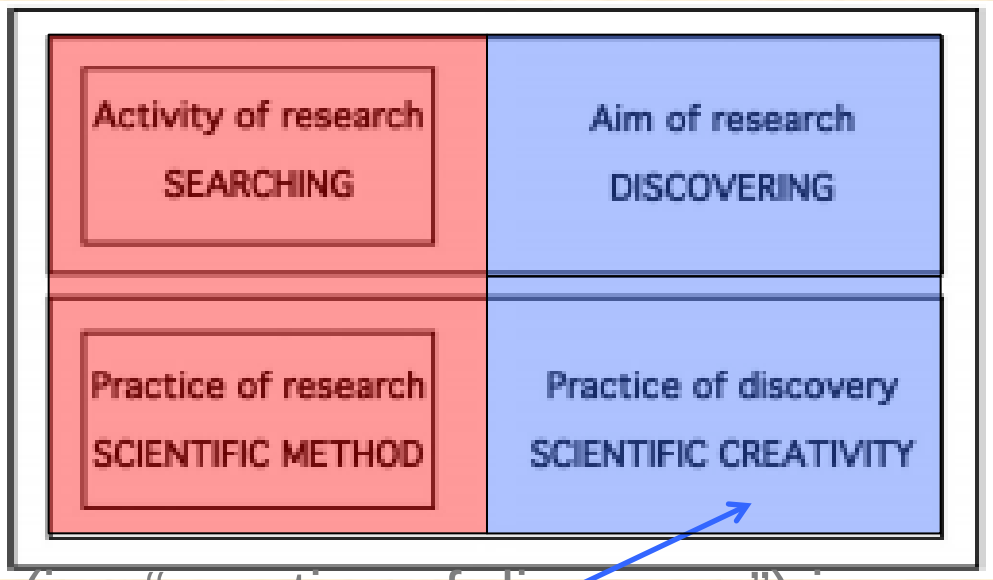
- training i…search", called sc…othesis testing
- My book …n scientific creativity, which is an essential condition of discovery



- Assumption: the discovery process, although largely *personal*, obeys some *general rules*
- that can be analysed
- on which actions can be based

Scientific research and discovery

- I defined scientific discovery (more simply: discovery) as
- finding, using imaginative skills (i.e. inventive abilities)
- new laws, new theories, or new paradigms
- without taking any assumption as being true *a priori*
- A discovery may be a major finding or a more modest achievement, but all discoveries share the same key characteristic: novelty (i.e. the quality of being new)
- The last point of the definition of discovery, i.e. without taking any assumption as being true *a priori*, distinguishes science from other intellectual activities
- example: astrology rests on the basic tenet that celestial objects influence people and events on Earth
- because astrology rests on a tenet that cannot be questioned by its practitioners, it is not a scientific activity

Scientific research and discovery

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- Science: universal knowledge acquired through discoveries
- Scientific research (more simply: research): activity of creating that universal knowledge, through discoveries

Nature of scientific discovery

- The aim of research is the same for all types of study
- studies driven by sole curiosity: fundamental research (e.g. any aspect of biology, chemistry, physics, or optics)
- studies targeted at problems or needs: targeted research (e.g. understanding the mechanisms of ocean acidification)
- studies devoted to resolving practical problems: applied research (e.g. improving the mass culture of microalgae)
- their aim is the same: finding something new (discovery)

- Because the number of natural phenomena is very large, perhaps infinite
- a discovery never results from randomly assembling facts or observations: making discoveries requires a special approach
- to make a discovery, a scientist must use a very powerful, special tool: his/her mind, i.e. thinking in an original way

Key role of imagination

- What determines the direction of science is
- primarily the creative imagination of researchers
- not the universe of facts which surrounds us
- Scientific publications can mislead early-career scientists as they do not show the role of creative imagination in discoveries: they are *reconstructions of findings*, *not reports* of how discoveries took place – this is because science is
- not the compilation of the *personal quests* of discovery of individual researchers
- the *universal knowledge* from discoveries (previous slides)
- Some researchers (although very few) have published, in addition to their scientific papers, books or essays in which they explained how they had made discoveries
- some philosophers of science have analysed these works
- I used the two types of publication when writing my own book

Caveat

- Previous slide*: some researchers have published books or essays in which they explained how they had made discoveries*
- Caveat

- even in cases where researchers have described their own paths to discovery, their introspective reports of creative thinking may be unreliable
- because self-reports are informed by the person's tacit theories, or prejudices
- introspection is looking into one's own mind, which shares an important feature with looking into anything else: to a large extent, you see what you expect to see

Imaginative skills

- Because scientific publications are logical reconstructions of findings
- most people think that science proceeds rationally from what is already known to the unknown (i.e. discoveries)
- too few people are aware of the essential role played by imaginative skills (i.e. inventive abilities) in the discovery process
- As mentioned a few slides before, the central characteristic of discovery is novelty, hence
- discoveries cannot be predicted from existing knowledge (indeed, if we could predict a discovery, we would make that discovery directly instead of going through the – often frustrating – process of conducting research)
- making a discovery requires something more than deductive logic: it requires imaginative skills (i.e. the

Steps of discovery

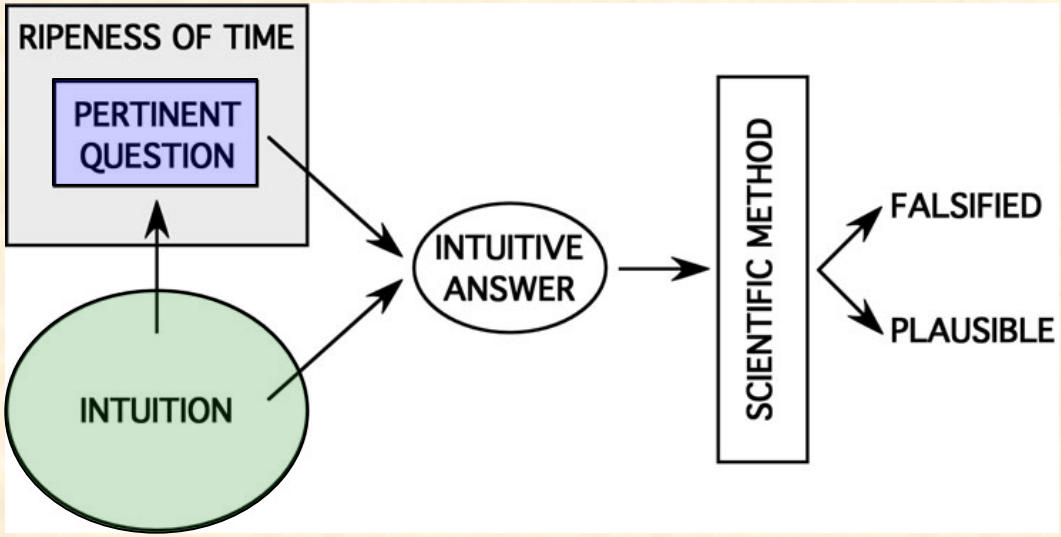
- Most research efforts do not lead to any discovery, but some researchers sometimes make discoveries
  How did they proceed when they made their discoveries?
- Books on that topic have described five general steps

1. preparation: becoming immersed in a problem
2. incubation: period during which ideas churn around in the mind, and unusual connections are likely to be made
3. insight: seeing a possible solution (intuition)
4. evaluation: deciding whether the insight is valuable and worth pursuing; because most insights lead nowhere, good researchers may be able to discard rapidly hopeless ideas
5. elaboration: stage that takes the most time and involves the hardest work, generally called research (last of the 5 steps)

- Does not tell what are the conditions to make a discovery

Conditions of discovery (1)

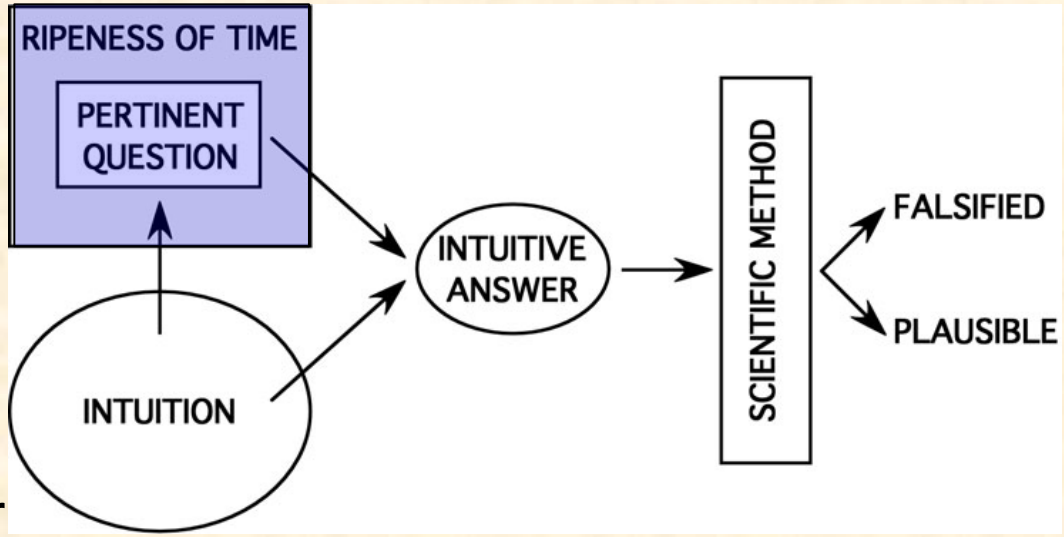
- What are the conditions required for researchers to sometimes make discoveries?
- My view: at least four components in making a discovery



1. Pertinent question

- first key step in discovery is to ask the right question, i.e. to see a problem where nobody saw one before
- this crucial step strongly calls on intuition (i.e. ability to understand or foresee something immediately, without using conscious reasoning)

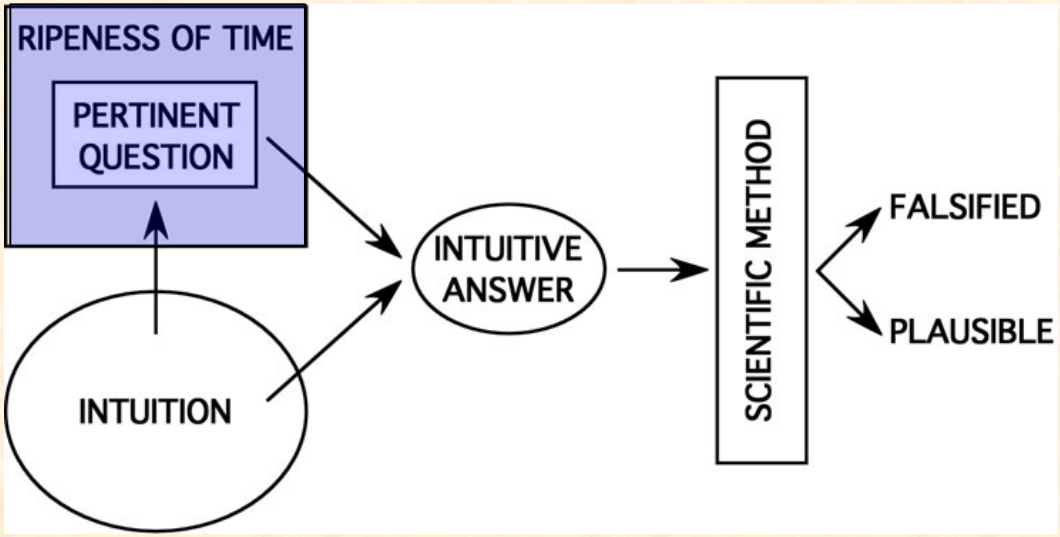
Conditions of discovery (2)



2. Ripeness of time
- the time must be ripe for addressing the question
- preliminary discoveries must have been made, *techniques must have become available* and/or a proper intellectual environment must have developed
- as the time ripens, the likelihood of the discovery increases: discoveries are often made almost simultaneously by independent researchers (sometimes causing quarrels)
- all needed elements are sometimes in place for a long time before making a discovery, e.g. selection by farmers during 10 000 years, but heredity only discovered in 1866 (Mendel; work rediscovered by three European scientists in 1900)

Conditions of discovery (2a)

- Previous slide (about the ripeness of time): *techniques must have become available*
- role of technological advances in making discoveries?

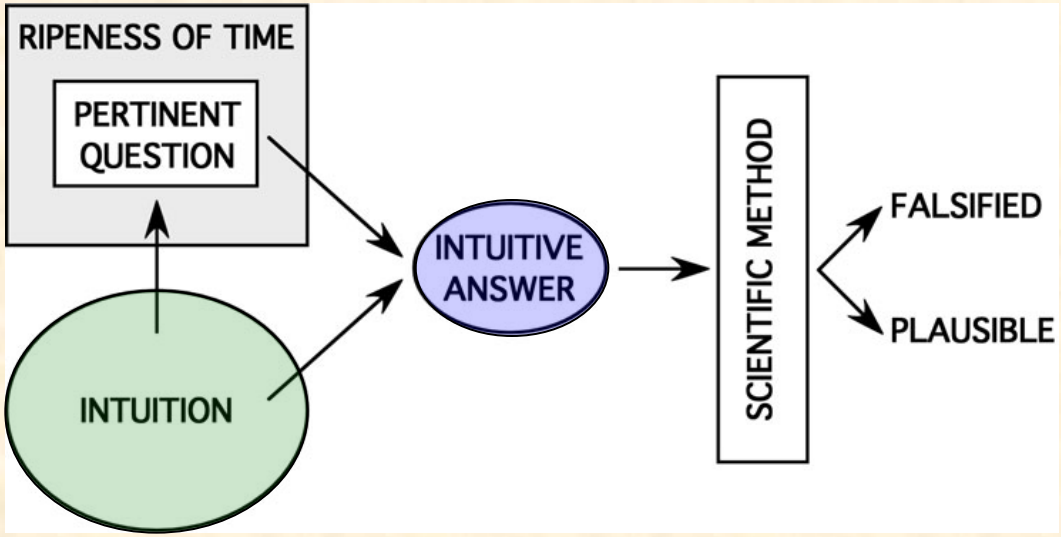


- I do not think that technology drives discovery directly
  - ➢ new technologies: direct or indirect results of scientific discoveries, i.e. both causes and effects of discovery
  - ➢ technology in itself does not lead to discovery: it is the creative use of technology, by someone who is trying to answer some question, that leads to discovery
- my view: interaction between technology and discovery, i.e. coevolution of concepts and instrumentation

Conditions of discovery (3)

3. Intuitive answer

- when the question is pertinent (component 1) and the time is ripe (component 2), one or several researchers often see the answer intuitively, i.e. without going through logical demonstrations



- answer is intuitive, i.e. intuition plays a key role not only in formulating scientific questions, but also in answering them
- most of the time, intuition leads to answers that must be later rejected

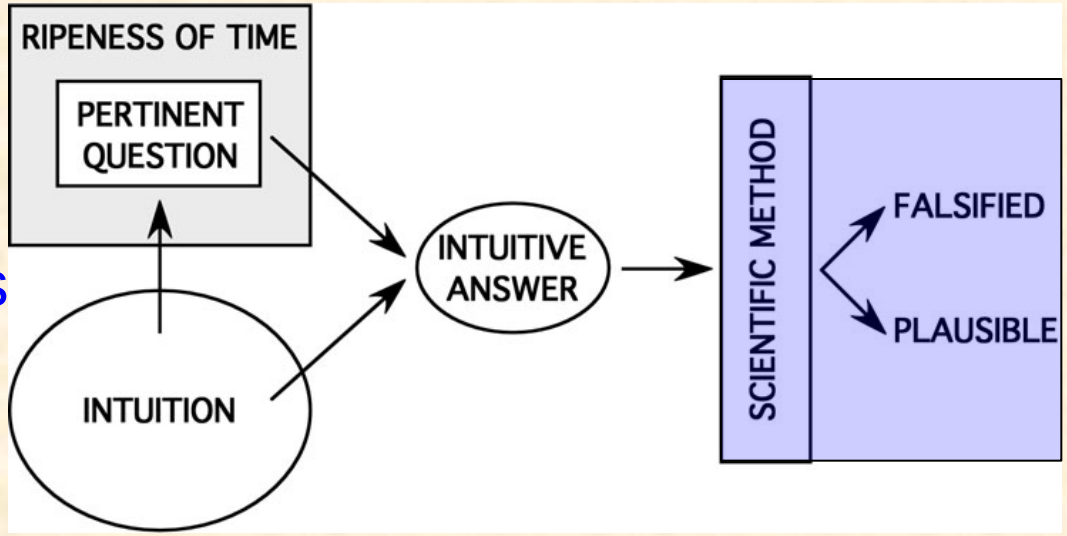
➢ in fact, sadly, most intuitive answers are wrong, but

➢ without intuition, no answer at all can be found

Conditions of discovery (4)

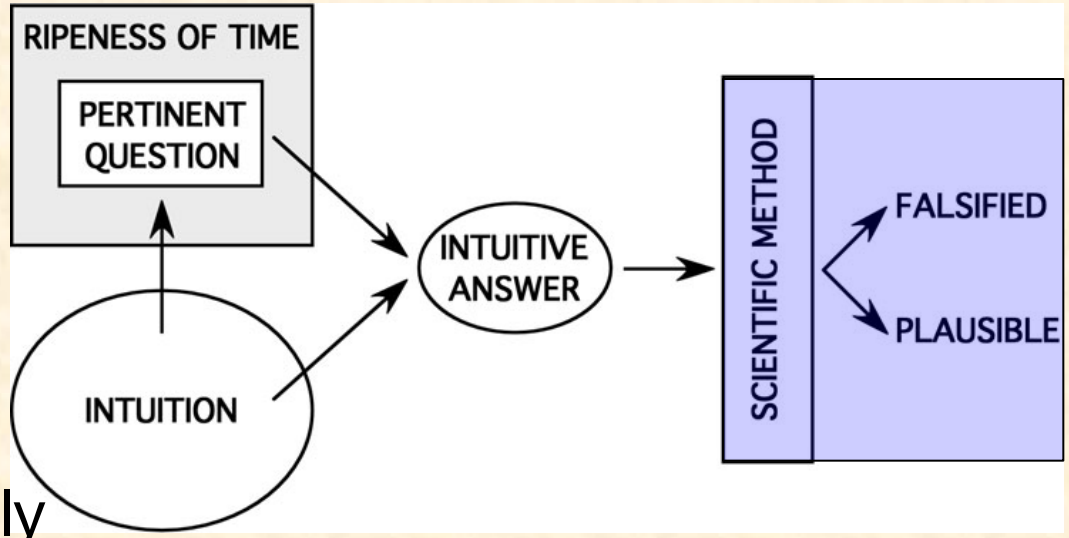
4. Scientific method

- the scientific method is used to reject or *accept as plausible* the answers provided by intuition
- the scientific method in itself does not generate answers: its role is to determine if the answers arising from intuition must be rejected (most of the time), or can be accepted as *plausible* (only rarely)
- very important: in natural sciences, one can never conclude that the answer given to a scientific question is true, i.e. the answer to a scientific question can only be rejected (i.e. falsified) or accepted as *plausible*



Conditions of discovery (4a)

4. Two points from the previous slide (about the scientific method)

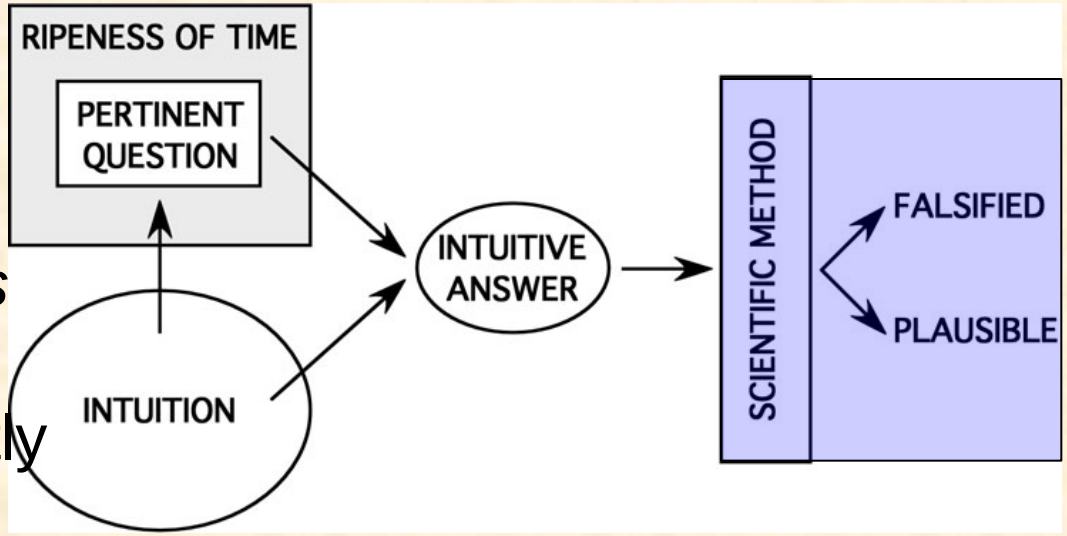


- *the scientific method in itself does not generate answers*
  - ➢ scientific method: the only part of the discovery process generally taught in universities
  - ➢ researchers (especially early-career) must find by themselves how to develop their own scientific creativity
- *the role of the scientific method is to determine if the answers arising from intuition must be rejected or can be accepted as plausible*
  - ➢ studies rejecting intuitive hypotheses are seldom published
  - ➢ fruitless hypotheses may be considered over and over again

Conditions of discovery (4b)

4. Additional point

- *The scientific method is used to reject or accept as plausible the answers provided by intuition*
- answers that we presently accept as plausible will eventually be challenged, and give way to new answers, themselves only plausible → transient nature of discoveries
- Well-known example: physics (mechanics)



- ➢ Newton (1687): space and time = absolute, i.e. space is independent of matter, and time passes uniformly
- ➢ Einstein (1905-1915): space and time are connected, and the structure of spacetime depends on the presence of matter
- ➢ Newtonian physics is correct when the speed of objects << c

Conditions of discovery (5)

- Does chance (luck) play a role in discovery?
- certainly not randomness, as explained in a previous slide
- perhaps serendipity: the finding of something valuable without it being specifically sought
  - ➢ only someone with a question in mind can take advantage of an unexpected event when it occurs
  - ➢ example: Newton drew an important conclusion from the falling of apples to the ground (i.e. gravity) because he was then seeking an explanation to the revolution of the Moon around the Earth (we will come back to Newton later)
- Louis Pasteur: “Fortune favours the prepared mind”

- Hence serendipity depends on a pertinent question, the ripeness of time, and an intuitive answer much more than on the occurrence of an inherently improbable event (i.e. chance)

Section's conclusions

- Conclusions of this section

- scientific research is an intellectual activity, which aims at making discoveries: the latter are creations of the mind
- scientific discoveries are transient, because the answers to questions about Nature are only plausible, never certain

➢ new discoveries, new techniques and/or new intellectual or social environments will eventually lead to challenging the answers that we presently accept as plausible

➢ some of the present answers will then be found incomplete or will be falsified, and give way to new answers, which will themselves be only plausible → transient nature of discoveries

➢ undergraduate students are often disappointed by this

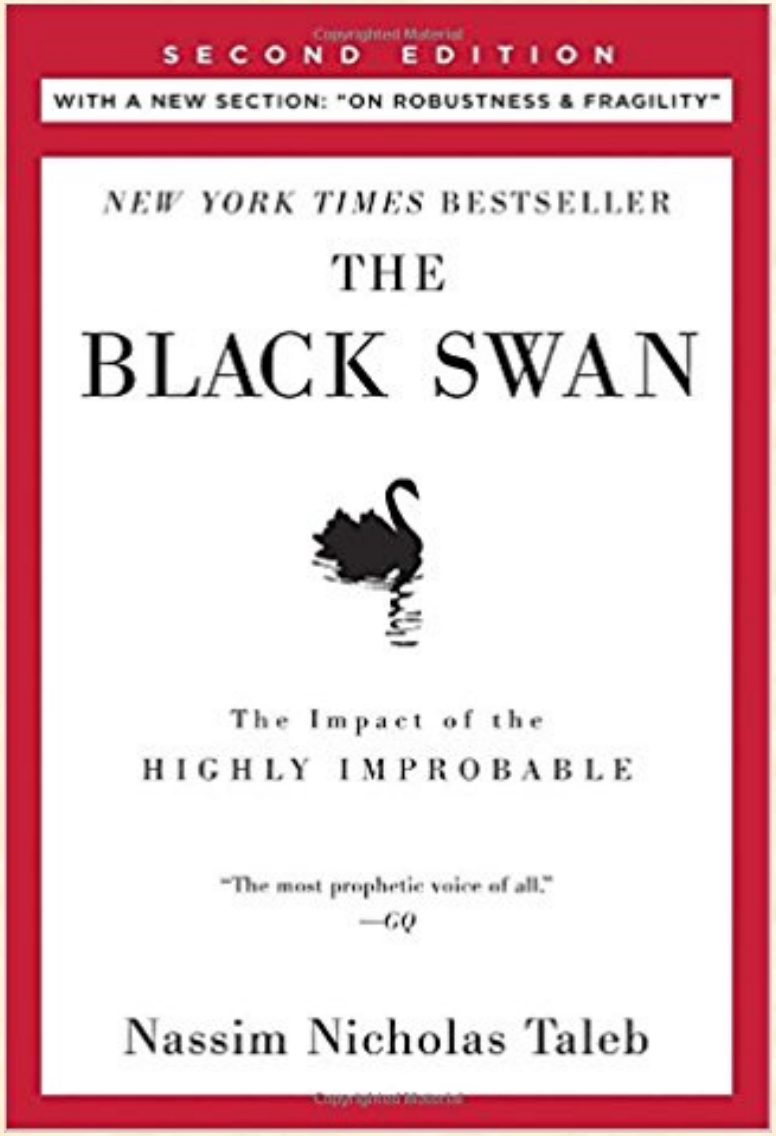
➢ however because of this, researchers can make discoveries during their whole career, from thesis to emeritus: science is the greatest window of opportunity for young people

A. Scientific research and discovery

B. Scientific discoveries as Black Swans (new: not in my 2004-2008 book)

The Black Swan hypothesis

- Economist and philosopher Nassim N. Taleb published in 2010 a book entitled The Black Swan
  - economic and/or social effects of highly improbable events, which he called Black Swans
  - refers to an ancient saying (back to the Romans) which presumed that black swans did not exist, and was proven false when black swans were discovered in Australia
- Book sales: 3 million copies



Black Swans: example

- Black Swan: event that is rare, has extreme impact when it occurs, could not have been imagined before it occurred, and can be easily explained after its occurrence
  - positive Black Swans: beneficial effects
  - negative Black Swans (more frequent): damaging effect
- Example of Black Swan: Fukushima nuclear disaster
  - suite of events that caused an energy accident at the Fukushima Daiichi Nuclear Power Plant in Japan in 2011
  - magnitude 9 offshore earthquake on 11 March 2011
  - reactors were not physically damaged by the earthquake
  - 13-m high tsunami overwhelmed the 10-m seawall
  - flooded the emergency generators that would have provided power to operate the pumps to cool the reactors
  - insufficient cooling led to meltdowns of three nuclear reactor, explosions, and the release of radioactive material

Black Swans and scientific discoveries

- Scientific discoveries are Black Swans
- Black Swan (Taleb): event that is rare, has extreme impact when it occurs, could not have been imagined before it occurred, and can be easily explained after its occurrence
- Black Swan (scientific discovery): breakthrough that has a major impact in a particular field of science

➢ rare event in the lives of most researchers
➢ major impact on the discipline
➢ not predictable, if not why searching instead of discovering?
➢ easily explained in publications, which are reconstructions

- Today: I use of one aspect of Taleb's book to analyse the place of discoveries (Black Swans) among the various types of research results

Scientific discoveries as Black Swans

- Taleb (2010, p. 365): 2 x 2 Table that describes the effects of decision making in terms of payoffs, where Black Swans are found in the 4th quadrant
- Here, I propose a 2 x 2 typology of research strategies, based on the types of expected results and the level of recourse to intuition, with discoveries in the 4th quadrant

	Intuition absent or wrong	**Intuition present and right**
Known results		
Unknown results		Scientific discoveries

Typology of research strategies (1)

	Intuition absent or wrong	**Intuition present and right**
Known results	New study may confirm previously known conclusions	
Unknown results		

- Research that simply confirms previous work can be sound, but does not result in much scientific progress

Typology of research strategies (1)

	Intuition absent or wrong	**Intuition present and right**
Known results	New study may confirm previously known conclusions	New study may evidence hidden conclusions
Unknown results		

- A study based on intuition which evidences conclusions that were hidden in previous works, e.g. meta-analysis of previous results, can be a real contribution to scientific progress

Typology of research strategies (1)

	Intuition absent or wrong	**Intuition present and right**
Known results	New study may confirm previously known conclusions	New study may evidence hidden conclusions
Unknown results	Study may disprove the anticipated conclusion, i.e. no discovery; most cases	

- In studies where the results are not known *a priori*, the application of the scientific method to novel ideas resulting from intuition may lead to disprove the anticipated conclusions, which happens in most cases

Typology of research strategies (1)

	Intuition absent or wrong	**Intuition present and right**
Known results	New study may confirm previously known conclusions	New study may evidence hidden conclusions
Unknown results	Study may disprove the anticipated conclusion, i.e. no discovery; most cases	Study may lead to a discovery (i.e. positive Black Swan); rare cases

- In studies where the results are not known *a priori*, intuition may lead to real discoveries, although in rare cases: these correspond to the concept of positive Black Swans of Taleb (2010)

Typology of research strategies (2)

	Intuition absent or wrong	Intuition present and right
Known results	New study may confirm previously known conclusions *Known knowns*	New study may evidence hidden conclusions *Unknown knowns*
Unknown results	Study may disprove the anticipated conclusion, i.e. no discovery; most cases *Known unknowns*	Study may lead to a discovery (i.e. positive Black Swan); rare cases *Unknown unknowns*

- Typology interpreted in term of knowns and unknowns
- Black Swans (discoveries) are a subset of the various types of research results, whose likelihood can be increased by using strategies that combine novelty and intuition

More about Black Swans

- More about Black Swans in research in the next edition of my book …

A. Scientific research and discovery
B. Scientific discoveries as Black Swans
C. Scientific creativity

Creative imagination

- Discoveries are products of the imagination of creative researchers (i.e. not products of technology by itself)
- everybody can see Nature, but the reality of facts is generally so powerful that it is difficult to imagine something beyond them
- one needs imagination to leap from the reality of Nature that surrounds us to making discoveries about Nature
- creative imagination combines three components, which will be fully explained in following slides
  these components are:
  - imagination and intuition
  - craftsmanship (i.e. expertise, skills): ability to use the scientific method
  - pleasure

Intuition

- Intuition is the basis of creativity in science
- creative researchers select, for example, some phenomena, processes or mechanisms that are often already known, but in which they intuitively sense new information
- historical example

➢ many of you in this room probably know the story of Isaac Newton seeing an apple falling from a tree, which led him to discover the laws of gravity (it seems that this story is true)

➢ the falling of an apple was not a new phenomenon, but because Newton has then seeking an explanation to the movements of celestial objects, he intuitively sensed original information in the falling apple

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  - ➢ the falling of an apple was not a new phenomenon, but Newton intuitively sensed in it original information
- truly creative researchers intuitively select the right elements, which allow them to make discoveries
- intuition is most often wrong and thus misleads researchers, but there is no discovery possible without intuition
- discovery = courage of following intuition to probable failure

Craftsmanship

- Intuition alone is not enough to achieve original works

- creativity requires in addition expertise and skills (called *craftsmanship*), i.e. the mastering of the scientific method

➢ scientists must learn from other scientists how to develop and test hypotheses (e.g. during M.Sc. and Ph.D. work)

➢ without the scientific method, a so-called scientific discovery could in fact only be a figment of imagination

- mastering the scientific method makes it possible to translate intuition into discoveries

➢ intuition alone is not enough to make a discovery, i.e. it also requires using the scientific method

➢ conversely, using the scientific method without intuition often produce sound works, but not original ones (i.e. no discovery)

➢ most published studies (including mine) report sound works but not discoveries

Pleasure

- The pleasure shared by creative researchers and those who enjoy their discoveries is an additional major characteristic of the discovery process

- pleasure (e.g. having a paper accepted in a top journal)

➢ sustains the creativity of researchers against the difficulties they often meet when producing the discoveries

➢ drives the researchers to share their works with others

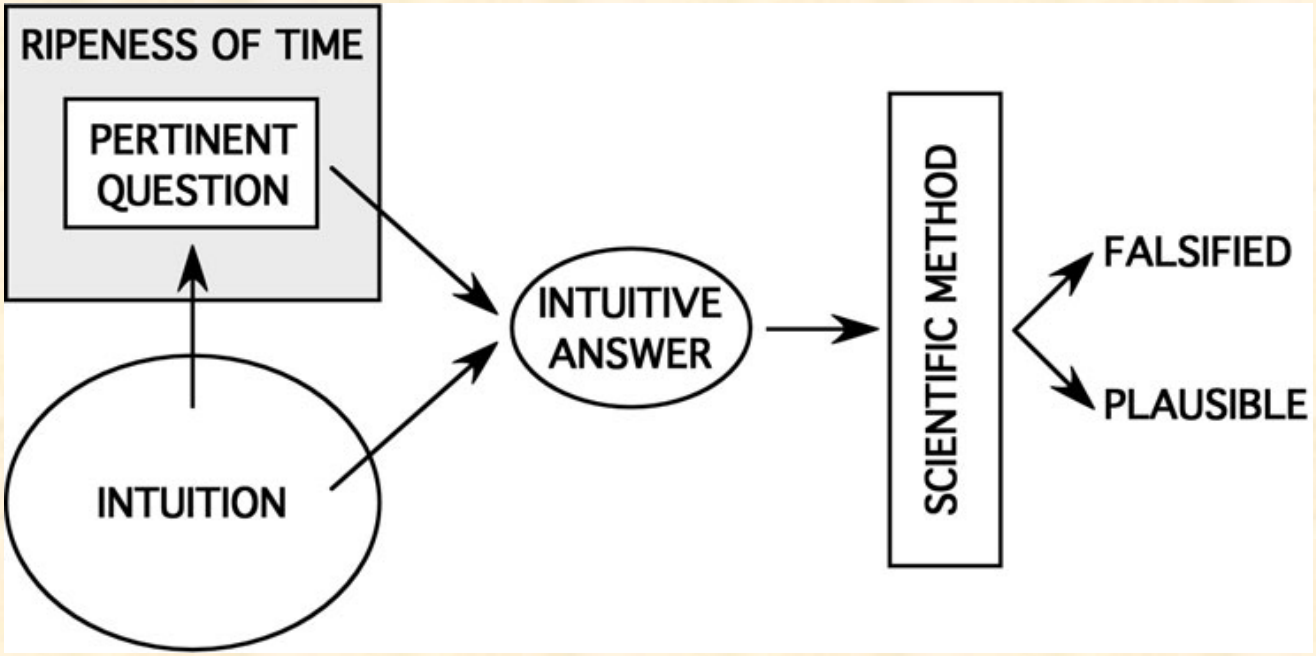
➢ leads society to support creative researchers

➢ plays an essential role in transforming the discovery process, which is an individual pursuit, into an activity that interests the society as a whole

- Robert Feynman (Nobel Prize in Physics 1965) wrote in a book: the pleasure of finding the thing out, the kick in the discovery, the observation that other people use my work [most researchers do not dare to admit their pleasure]

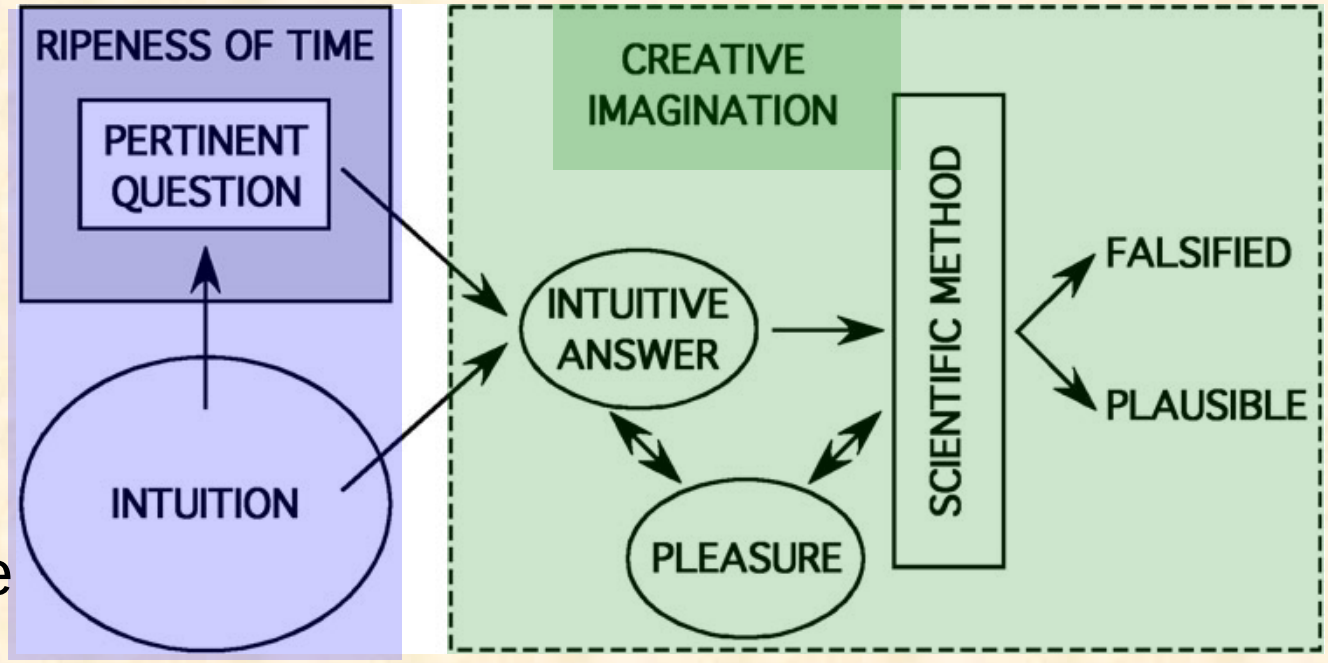
Complete discovery process

- The description of the discovery process (previous section) is completed by the present analysis of creative imagination



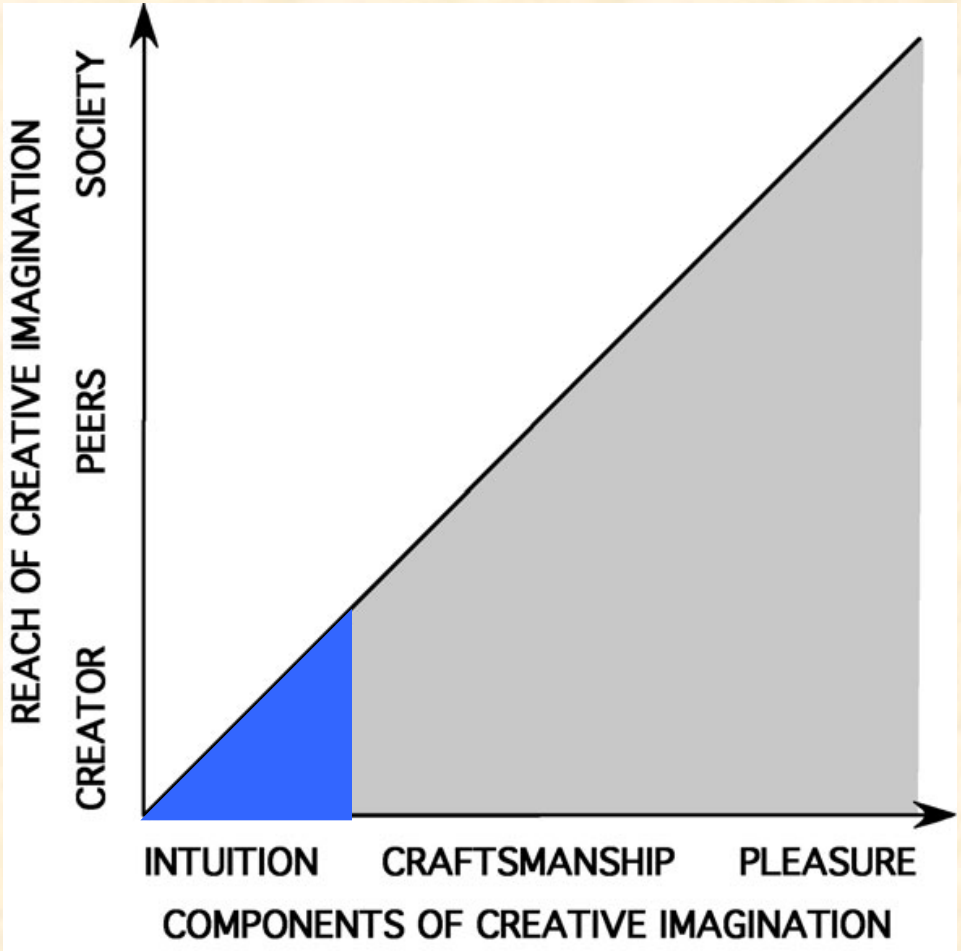
Complete discovery process

- The description of the discovery process (previous section) is completed by the present analysis of creative imagination
- The process leading to discoveries
  - requires (previous section): (1) a pertinent question, whose formulation strongly involves intuition, (2) the ripeness of time, and (3) creative imagination
  - creative imagination (this section) combines (a) intuition, (b) the scientific method, and (3) pleasure



Reach (or range) of creation (1)

- Previous slides: scientific creativity progressively extends from individual researchers (intuition) to society (pleasure)
- Figure: reach (or range) of creative imagination (Y) plotted as a function of its three components (X)

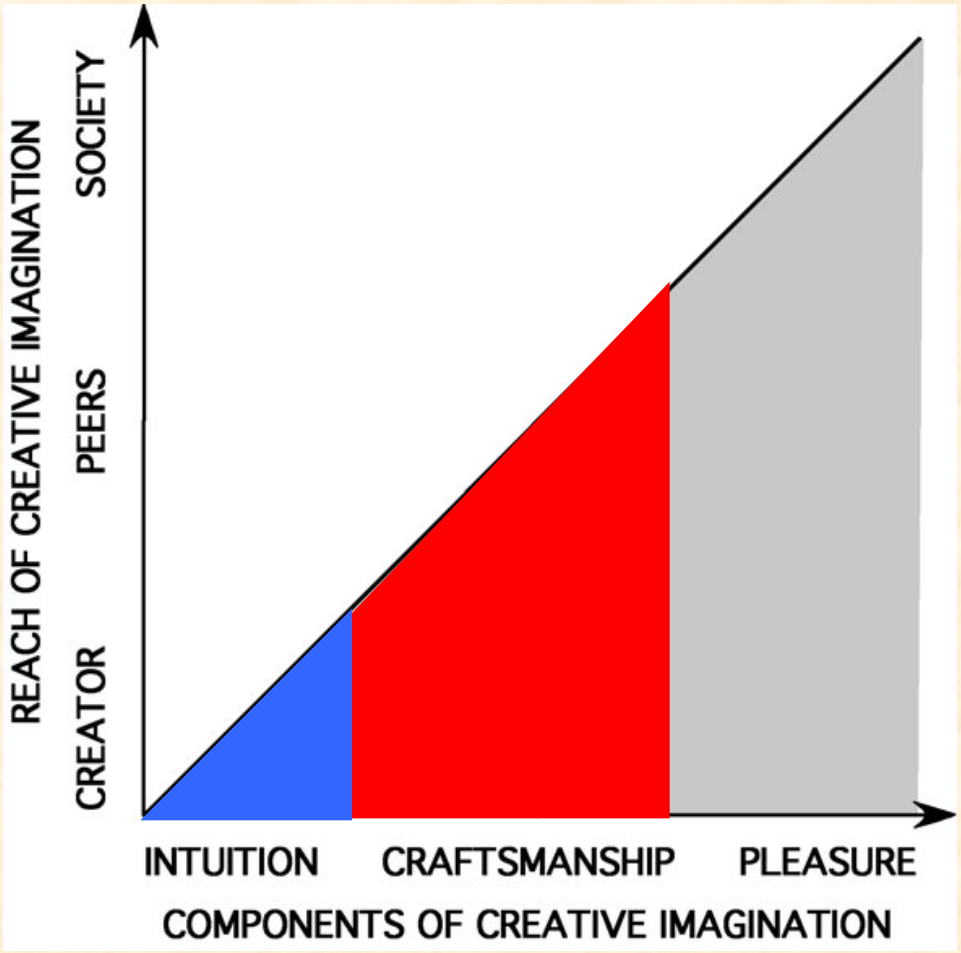


- Intuition is a personal trait, which allows researchers
  - to see information where other people do not
  - to use information for selecting relevant elements of Nature and assembling them in original ways

Reach (or range) of creation (2)

- Crafts or methods must be learned from peers (e.g. students learn the scientific method from their theses supervisors)

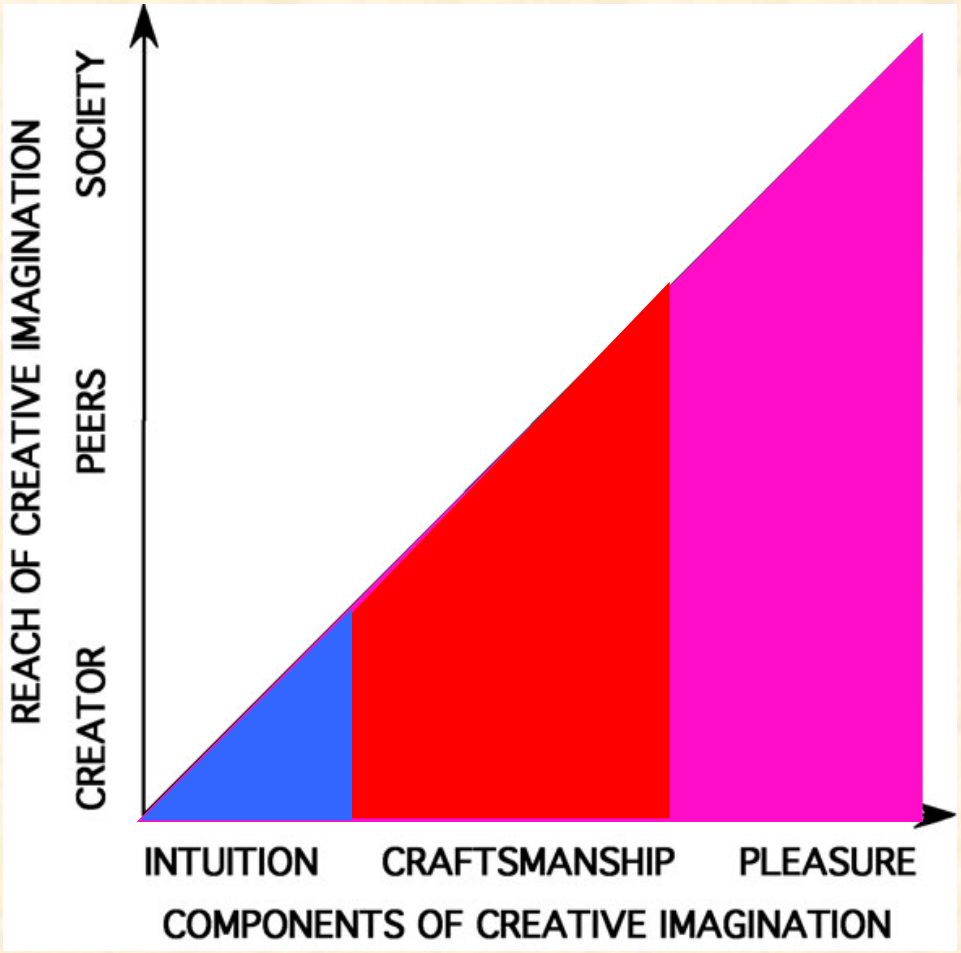
- during their university years, scientists become part of peer groups
- as the career progresses, the peer group grows and changes: a few close friends, and a circle of colleagues who researchers meet more or less regularly
- generally, researchers do not work alone



Reach (or range) of creation (3)

- Pleasure transforms discovery into an activity that interests the society as a whole (explained previously)
- Shows that creativity
  - is not a social luxury
  - plays a fundamental role in societies
- Long-term maintenance of civilisations requires societies to support sustained creativity (in scientific research, arts, literature, etc.)

  [some implications in the next slide]



Section's conclusions

- In order to maximise the likelihood of discoveries, educational, research and social systems must provide conditions that favour the three components of creative imagination
  - protect, praise, and encourage intuition
  - promote and implement the use of the scientific method
  - put pleasure at the centre of scientific activities
- Scientific method
  - difficult to apply by researchers to their own intuitive answers (H_0), because the aim of the method is to reject these answers
  - implemented through a very strict approach developed over time to ensure that published discoveries have been subjected to rigorous testing; this is achieved through
    - ➢ the training of future scientists: lectures and mentoring
    - ➢ reviews of manuscripts by peers, i.e. independent researchers

A. Scientific research and discovery
B. Scientific discoveries as Black Swans
C. Scientific creativity
D. Creative skills

Developing creative skills

- Different ways that can be used to develop creative skills, i.e. to develop one's likelihood of making discoveries

- in my book: one chapter
- here, brief description of some approaches

➢ heuristics
➢ three special methods
➢ writing scientific papers

Heuristics

- Solving scientific problems is a creative activity
- ability can be improved by using heuristics
- a heuristic (noun): technique that provides a way of thinking about a problem, which follows the paths most likely to lead to the goal, leaving less promising avenues unexplored
- very popular in mathematics; also exist in other sciences
- objective: develop the ability not only to answer posed problems, but also to pose answerable problems, i.e. to generate testable hypotheses

- Examples: drawing a diagram, writing an explicit equation, reformulating the problem, examining special cases, simplifying or generalising the problem, constructing an analogous problem, and exploiting related problems in neighbouring scientific fields [for more, see my book]

Special methods

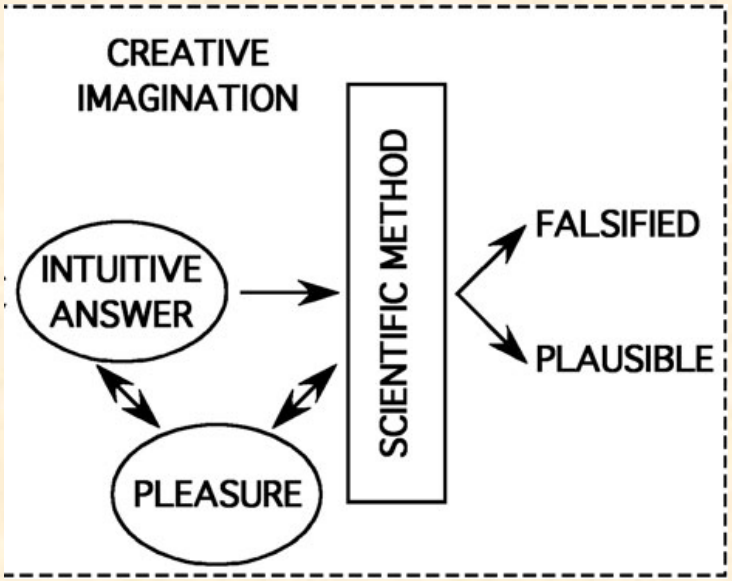
- There exist special methods to approach scientific problems: I summarise here three methods that are explained in my book [see my book for details]
- Dimensional analysis
- can find the general form (i.e. equation) of the relationship among any set of variables
- provides tools that put the mind on the discovery track
- Theoretical analysis
- considers scientific problems from a theoretical viewpoint
- analysing the data using a new theory can lead to discovery
- Development of concepts and models
- combination of theoretical analysis and model development
- especially useful for the re-analysis of information that exists in large databases

Writing scientific papers: emergence

- Writing scientific papers is a creative activity: final version of a scientific paper is often very different from the original idea of the author(s)
- Often when writing, a novel idea, which the researcher had not considered before, seems to emerge from the text itself
  - the new angle provided by this unexpected, new idea sometimes becomes the main thrust of the paper
  - when this occurs, it may lead to the reorganisation of the whole manuscript, reanalysis of the data, and rewriting part of the text
  - the act of writing can be seen as a progression towards *higher organisation* of the ideas, which sometimes favours the *emergence* of original thoughts that could not be predicted at the start of writing (system theory: emergent properties as the organization of a system increases)

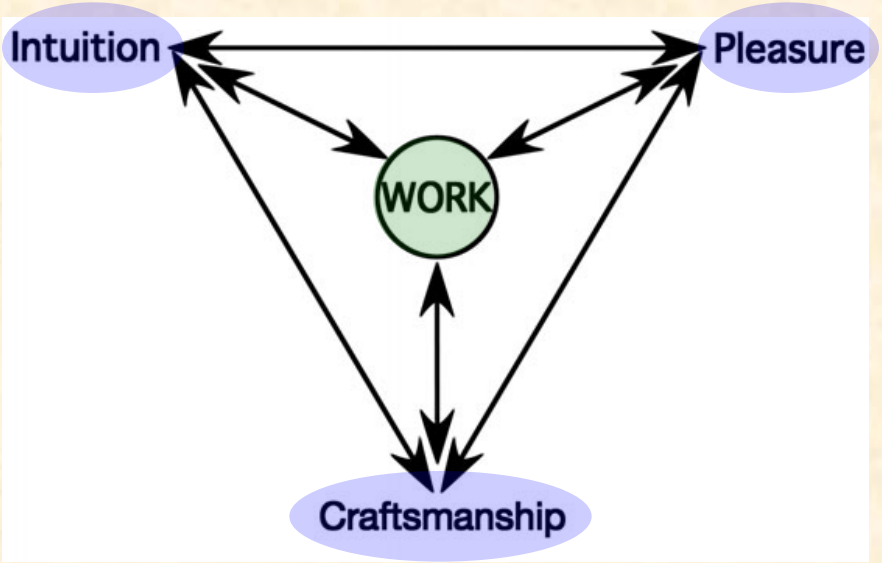
Writing scientific papers: inspiration

- Previous slide: the three components of creative imagination are intuition, craftsmanship and pleasure



Writing scientific papers: inspiration

- Previous slide: the three components of creative imagination (i.e. intuition, craftsmanship and pleasure)
  - here: interact continuously with one another during the writing of an original paper
  - and the text itself (work) becomes a term of the interaction



- As the writing progresses, the intensities of the interactions among the four terms change continually
  - this process is called inspiration by psychologists
  - inspiration is defined as the creative drive of researchers (drive: urge to attain a goal)
- Most efficient way to develop original scientific ideas: to write

Writing scientific papers: pleasure

- Writing is central to creative imagination in science
  - in a large proportion of the studies, the most original or interesting ideas appear at the time of writing
  - I strongly recommend to start writing *early* during a study
  - some researchers do not like writing (especially in a foreign language), and therefore delay it as much as possible
  - it is natural to dislike activities one does not master: becoming good at writing requires actually doing it
  - the more we write, the better we become at it, and thus the more we enjoy writing
- Writing is a great joy at all times, when properly mastered
  - when this skill leads to discovery, it provides great pleasure
  - the individual pleasure of discovery is enhanced by peer recognition, and by reaching readers all over the World

Section's conclusions

- Creative skills can be developed
- Writing scientific papers

- purpose: to be read, to influence readers, and thus to contribute to the development of science
- to attract readers, researchers must not only report interesting science, but also use a pleasant writing style
- in order to write precisely and elegantly, one must master the written language, as a tool not only for communication but also as a tool for discovery (inspiration)

- In every scientific paper, there should be a single central idea

- as readers, we all prefer papers with a clear focus
- as authors, we often wish to put several messages in a paper
- this can be avoided by remembering how much pleasure we derive from well-focused papers

A. Scientific research and discovery
B. Scientific discoveries as Black Swans
C. Scientific creativity
D. Creative skills
E. Public outreach

Public outreach of research

- Characteristics of research and discovery from the previous sections can be used to analyse research-related activities
- in my book: education, funding of research, and others
- example here: public outreach of research
- Successful public outreach of research is important for both
- attracting bright youngsters to scientific careers
- ensuring sustained public support of research
- Pubic outreach is often largely or exclusively based on three aspects of science that, in my view, turn people off:
- insistence on the rationality of the scientific approach
- awed admiration of the magnitude of scientific knowledge
- focus on utilitarian facets of science
- Next slides: brief discussion of these three aspects, and suggestions of possible solutions for doing better outreach

First problem: description

- First problem: insistence on the highly rational nature of the scientific approach
- Discovery requires the combination of intuition, pleasure and the scientific method (creative imagination)
- insisting on the latter facet of creativity (scientific method) provides a very distorted picture of science and scientists
- roles played in discovery by intuition and pleasure are often a well-kept secret among creative scientists
- When researchers outreach to the public, they often show only their rational facet and hide their intuition and pleasure
- showing only the rational facet of discovery misleads the public as to the nature of scientific discovery
- produces a gulf between researchers and other people, who may admire scientists but have no wish to emulate them

First problem: possible solution

- Outreach should show researchers as true creators
- Key messages in outreach
- the aim of research is discovery
- discoveries are made by combining intuition, the scientific method and pleasure
- discoveries are creations of the imagination of researchers
- researchers are both logical, highly trained, rational individuals, and imaginative, talented, enthusiastic creators
- Increasing problem and possible solution
- public increasingly think that scientific research is difficult and mysterious, if not dangerous, and see researchers as abnormal, perhaps threatening people
- outreach should convey the message that scientific research is an exciting activity, conducted by interesting people

Second problem: description

- Second problem: awed admiration of the magnitude — quantity, diversity and complexity — of scientific knowledge
  - scientific knowledge is often presented to the public as an immense and complex body of firmly established and interconnected laws, at the periphery of which discoveries are made
  - because of this, most people think that improving such a formidable construct is nearly impossible.
- Scientific knowledge should be shown as it truly is
  - a construct of human minds, in which all present answers are provisional
  - because scientific discoveries are transient, scientific knowledge is provisional
  - it follows that scientific discoveries are within the reach of those who are willing to use creative imagination

Second problem: possible solution

- Outreach should explain that the body of scientific knowledge, although formidable, is transient, and researchers should avoid at all costs behaving as if they possessed absolute truth
  - science is a continuously evolving product of human minds
  - discoveries are within the reach of those who are ready to apply creative imagination (intuition, method and pleasure) to scientific questions
- Outreach should convey the message that science is interesting, and scientific discoveries are made by normal human beings, not weirdoes

Third problem: description

- Third problem: sometimes exclusive focus on utilitarian facets of research
  - no technological progress without scientific discoveries, but the utilitarian aspects of science are not integral to creative imagination
  - usefulness of scientific studies is not a necessary condition for obtaining sustained public support over several decades
- I think that the degree of public support of various fields depends fundamentally on their dream potential
  - dreaming beyond day-to-day contingencies is essential to both individual sanity and social progress
  - outreach must therefore be very careful not to kill the dream quality of science by focussing primarily on its utilitarian facets

Third problem: possible solution

- There is no point in focussing outreach exclusively or even primarily on the utilitarian facets of science
- best way to attract people to something is to tell them that it is pleasurable, not necessarily that it is useful
- People want to escape the utilitarian aspects of life into private or collective dreams at least a few hours every day
- useful facets of discoveries can be presented in such a way as to sustain pleasure, not replace it
- outreach should present science as sustaining our dreams about Nature, and show that many useful facets of discoveries are fascinating

Section’s conclusions

- Characteristics of research and discovery from the previous sections can be used to analyse research-related activities
- these include education, funding of research, and the public outreach of research
- successful public outreach contributes to attract bright youngsters to scientific careers, and to ensure the sustained public support of research
- Three aspects of pubic outreach that, in my view, turn people off, can be improved by taking into account the characteristics of research and discovery
- insistence on the rationality of the scientific approach
- awed admiration of the magnitude of scientific knowledge
- focus on utilitarian facets of science

A. Scientific research and discovery
B. Scientific discoveries as Black Swans
C. Scientific creativity
D. Creative skills
E. Public outreach
F. Scientific research as a career

Other creative activities than research

- Students and young scientists should know that most researchers devote part of their time to scientific activities other than research: three types of such other activities
- teaching: in universities, normal complement of research
- management: wide range of activities that facilitate research and/or teaching, e.g. direction of research teams or laboratories, edition of scientific journals, leadership of learned or professional societies, direction of teaching programmes or departments
- consulting: production of expert assessments for a variety of establishments, which include universities and research organisations, funding organisations, professional journals, learned societies, and corporations
- Who is doing which type of activity, and when?

Research and other scientific activities

	Early career	Mid-career	Late career
Research	+++	++	+
Teaching, management, consulting	+	++	+++

- Table: schematic representation of the evolution of scientific careers, for three stages of the career and two types of activity (i.e. research, and other activities)

- in early career
  - ➢ large part of the time is dedicated to research
  - ➢ some time is devoted to teaching, management and consulting
- as the career progresses, increase in the proportion of the time dedicated to activities other than research

Time resource

	Early career	Mid-career	Late career
Research	+++	++	+
Teaching, management, consulting	⊕	++	+++

- Even at the beginning of their careers, researchers generally devote some part of their time to other tasks than research
- as the career progresses, the time resource becomes increasingly strained: less and less time to do more and more
- hence it is crucial for young researchers to launch important scientific projects as early as possible in their careers, when they still have much time for research

Time resource

	Early career	Mid-career	Late career
Research	+++	++	+
Teaching, management, consulting	+	++	+++

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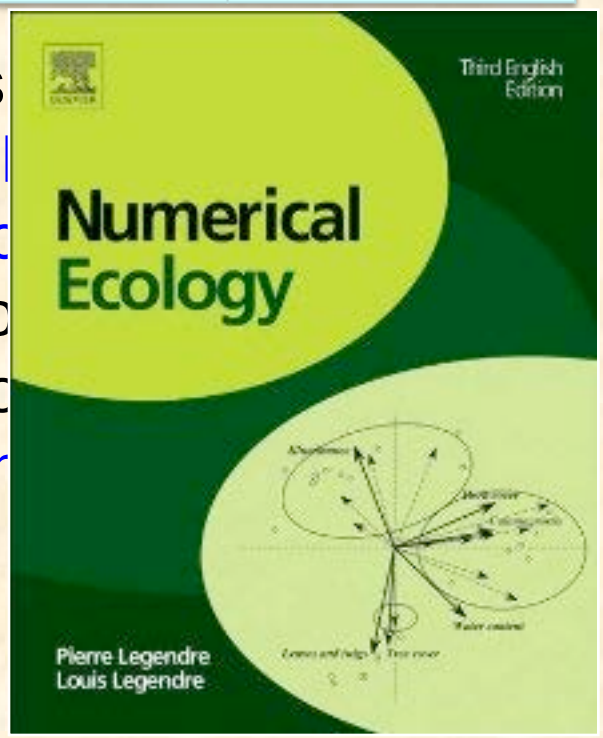
  increasingly strained: less and less time to
- hence it is crucial for young researchers to
  scientific projects as early as possible in th
  they still have much time for research
- example: I published the 1st edition of my
  book *Numerical Ecology* 8 years after
  completing my PhD (after 5 editions: >18,000 citations)



Section’s conclusions

- During a scientific career, younger scientists can generally dedicate most of their time to research, and as the career progresses, the time resource becomes increasingly strained: less and less time to do more and more
- It is important for young researchers to launch important scientific projects as early as possible in their careers, when they have much time for research

A. Scientific research and discovery
B. Scientific discoveries as Black Swans
C. Scientific creativity
D. Creative skills
E. Public outreach
F. Scientific research as a career
General conclusions

General conclusions

- Scientific research is an intellectual activity, which aims at making discoveries
- Discoveries are creations of the mind
- Young people can make important discoveries
- The three components of creative imagination are: intuition, the scientific method, and the pleasure of making and sharing discoveries
- Creative skills can be developed
- It is important to start writing early during the course of a study
- The act of writing can be a tool for discovery (inspiration)
- Young researchers should launch important projects as early as possible in their career
- Research can be very demanding but it is also very rewarding

Thank you very much for your kind attention

Enjoy the Villefranche Oceanography Laboratory

Part 2
Scientific research and discovery:
Process and practice
A. Scientific research and discovery
B. Scientific creativity
C. Creative skills
D. International research

Various aspects of international research

- In my book, I devote a chapter to international research, where I examine
  - ➢ the motivations of international research
  - ➢ how to conduct international research
  - ➢ how to prepare for international research
- scientists especially interested in international research could read that chapter
- today, I will briefly review the last topic, i.e. preparing for international research, as it may be of special interest to students and young researchers

Preparation for international research (1)

- University students and young researchers often wonder how to prepare for international research
- International research requires both long- and short-term preparation: various steps are summarised in the next slide

Preparation for international research (2)

Preparation	Means
Long-term	
High competence in one's field of science	University and personal
Mastering the English language	Pre-university and/or personal
Some knowledge of other languages	Pre-university and/or personal
Solid background in world geography and history	Pre-university and/or personal
General culture, i and table manners	ty and/or personal
Knowledge of international politics and economy	Pre-university and/or personal
Shorter-term	
Knowledge of the collaborative research	Personal; research officers
Characteristics of the countries involved	Personal; Foreign Affairs, embassies
Characteristics of the foreign partners	Personal; Foreign Affairs, embassies

We will analyse this Table step by step

Preparation for international research (3)

Preparation	Means
Long-term	
High competence in one's field of science	University and personal

- In the long term

- the best preparation for international research is to become and remain highly competent in one's field of science
- this professional competence is

➢ acquired through university education

➢ continuously improved through research

Preparation for international research (4)

Preparation	Means
Long-term	
High competence in one's field of science	University and personal
Mastering the English language	Pre-university and/or personal

- Additional long-term preparation includes
- mastering the English language, both spoken and written, which is useful to communicate with researchers in all countries and with at least some people in most countries

Preparation for international research (5)

Preparation	Means
Long-term	
High competence in one's field of science	University and personal
Mastering the English language	Pre-university and/or personal
Some knowledge of other languages	Pre-university and/or personal

- Additional long-term preparation also includes

- getting acquainted with other languages than English, especially if staying in countries or regions where English is not widely spoken

Preparation for international research (6)

Preparation	Means
Long-term	
High competence in one's field of science	University and personal
Mastering the English language	Pre-university and/or personal
Some knowledge of other languages	Pre-university and/or personal
Solid background in world geography and history	Pre-university and/or personal

- Additional long-term preparation also includes

- acquiring a solid background in World geography and history, in order to understand and enjoy the countries visited, and to avoid gross blunders

Preparation for international research (7)

Preparation	Means
Long-term	
High competence in one's field of science	University and personal
Mastering the English language	Pre-university and/or personal
Some knowledge of other languages	Pre-university and/or personal
Solid background in world geography and history	Pre-university and/or personal
General culture, including arts, literature and table manners	Pre-university and/or personal

- Additional long-term preparation also includes

- being conversant with such aspects of general culture as the arts and literature, in order to enjoy the experience abroad and easily fit in foreign countries

Preparation for international research (8)

Preparation	Means
Long-term	
High competence in one's field of science	University and personal
Mastering the English language	Pre-university and/or personal
Some knowledge of other languages	Pre-university and/or personal
Solid background in world geography and history	Pre-university and/or personal
General culture, including arts, literature and table manners	Pre-university and/or personal
Knowledge of international politics and economy	Pre-university and/or personal

- Additional long-term preparation also includes

- developing a current knowledge of international politics and economy, so as to understand the events occurring in foreign countries and be able to discuss them with colleagues there

Preparation for international research (9)

Preparation	Means
Long-term	
High competence in one's field of science	University and personal
Mastering the English language	Pre-university and/or personal
Some knowledge of other languages	Pre-university and/or personal
Solid background in world geography and history	Pre-university and/or personal
General culture, including arts, literature and table manners	Pre-university and/or personal
Knowledge of international politics and economy	Pre-university and/or personal

- Additional long-term preparation is generally considered to be part of pre-university education and/or personal culture
- not provided by most universities within science programs
- personal responsibility of researchers: often not easy

Preparation for international research (10)

Preparation	Means
• In the shorter term - one must scrutinise the aims, rationale and research plans of the intended or on-going international collaboration - this may be facilitated by research officers in funding agencies and organisations such as universities - key component of short-term preparation is personal work	
Shorter-term	
Knowledge of the collaborative research	Personal; research officers
Characteristics of the countries involved	Personal; Foreign Affairs, embassies
Characteristics of the foreign partners	Personal; Foreign Affairs, embassies

Preparation for international research (11)

Preparation	Means
Characteristics of the countries involved	Personal; Foreign Affairs, embassies
Characteristics of the foreign partners	Personal; Foreign Affairs, embassies

- Additional short-term preparation includes
- studying the characteristics of the countries involved in the collaboration, e.g. geography and history; political, economic and social organisation; culture; food and drinks
- Ministries of Foreign Affairs and/or embassies can often provide information that would be difficult to get otherwise
- key component of short-term preparation is personal work

Preparation for international research (12)

Preparation	Means

- Short-term groundwork also includes
- developing good knowledge of the foreign partners, e.g. organisation of research, stature and key publications of researchers
- national science agencies and embassies often prove useful in this respect
- key component of short-term preparation is personal work

Characteristics of the foreign partners	Personal; Foreign Affairs, embassies

Section’s conclusions

Preparation	Means
Long-term	
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Characteristics of the foreign partners	Personal; Foreign Affairs, embassies

- The experience of international collaboration
  - is very rewarding when successful
  - can be very frustrating when fruitless
- Because universities and research organisations generally do not contribute actively to preparing science students and young researchers to international collaboration
  - those interested in international research must seize all opportunities to improve their knowledge of languages and world affairs, and their general culture
  - given that non-scientific knowledge is often an important component of success in international research