„Innovation“ and „Societal Impact“ in Natural Sciences

Research and **education** in science

versus

Societal and **political** expectations

A **look back** and **an attempt to learn some lessons** from the past**.**

A physicist’s perspective.

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„Innovation“ and „Societal Impact“ in Natural Sciences

Society and politicians are increasingly impatient and expect the immediate usability and economic impact of research.

They lose sight of the fact that some of the most revolutionary changes in our knowledge and lives came from research which was not aiming at all at what the result and final impact turned out to be.

Employability of graduates is of course a major goal of university education. But what makes graduates employable?

From Basic Research to Innovation

I. Can **major innovations** be planned?
   A case study looking at a few discoveries which have changed our lives
II. A question of **time**: Time from first idea to product
III. Education, Awareness and Imagination
IV. Tools for transition from discovery to application
V. Conclusion for science funding and decision making

I. Can major innovations be planned ?

The answer is (mostly) “No”. Furthermore, the applications were not always immediately obvious.

Examples to illustrate the point

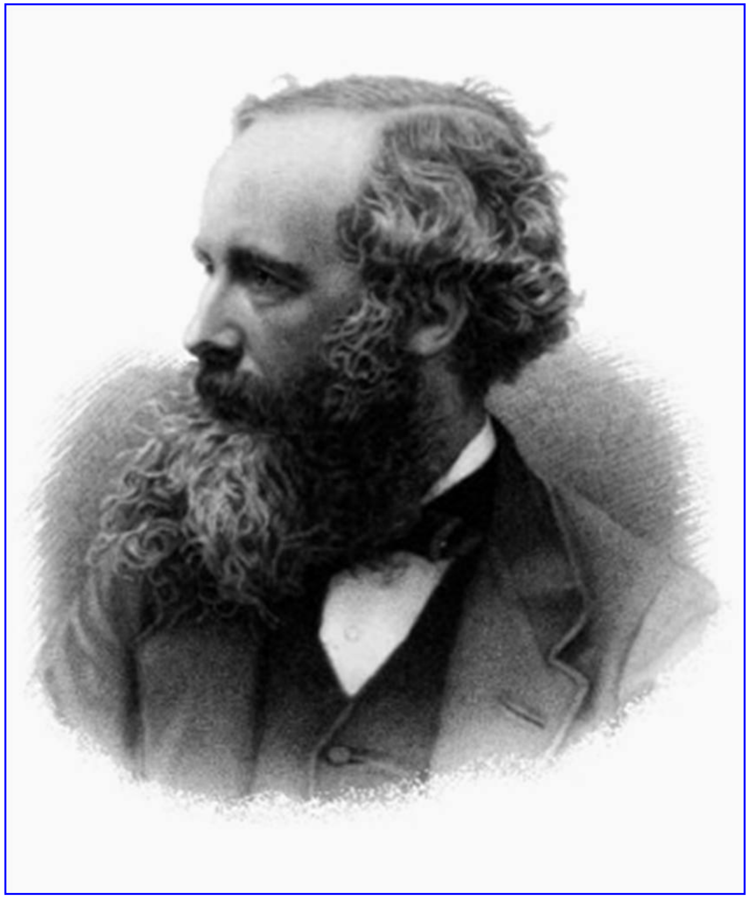
1. Electromagnetic waves
2. Physics and Life Sciences
3. Physics and Electronics
4. Lasers
5. Physics and life style

1. Electromagnetic Waves

James Clerk Maxwell:

Building upon the discovery of many other scientists (Ampère, Faradey, ...) Maxwell developed a set of four equations which describe the relation between electric fields, magnetic fields, electric charges and current.

In ~ 1865 he concluded, that the solution of his equations were electromagnetic waves which travel with the speed of light.



H. Hertz observed these waves in 1888

To Remember

- Hertz originally **did not try the prove** Maxwell‘s theory, but was inspired for his experiments by the work of Helmholtz related to electrodynamics. (Letter Hertz to Helmholtz).
- H Hertz **did not have possible applications in mind** when he pursued his ideas.
- Asked which **consequences** his findings would have he replied: „Probably none“.
- Faraday was asked a **similar question**.
- The research of H. Hertz was **inspired by** questions concerning **basics concepts** and relations, but became the basis for numerous applications without which today‘s life would be unimaginable.

Consequences for Technology and Science

- **Technology**
  - Radio
  - TV
  - Communication
  - Radar
  - Microwaves in the kitchen

- **Science**
  - The concept that a field is linked with a force has deeply influenced physics
  - Radioastronomy und cosmology

Time until major applications: > 50 years

2. Physics and Life Sciences

X-rays: Conrad Wilhelm Roentgen

He studied the properties of the electric current

He found the x-rays

He understood immediately the potential of x-rays in applications:

From medicine to science, manufacturing and security

Time until major applications: years

Physics and Life Sciences

- X-rays in life sciences:
  classical applications (diagnostics)
  Structural analyses (DNA, molecular structures, …)
  Irradiation

- Superconductivity
  From understanding the flow of currant to applications such as MRI
- Magnetic Resonance Imaging
  From understanding the behaviour of atomic and molecular dipoles in changing electromagnetic fields to imaging of the human body
- Ultrasound, lasers
- etc.

Time until major applications: varying, > 50 years

3. Physics and Electronics

Max Planck in 1900:

Idea of quantum physics emerged from trying to describe theoretically the shape of the radiation spectrum of a hot body, which just had been measured with unprecedented precision.

Discovery that energy is quantised.

Role of quantum physics:

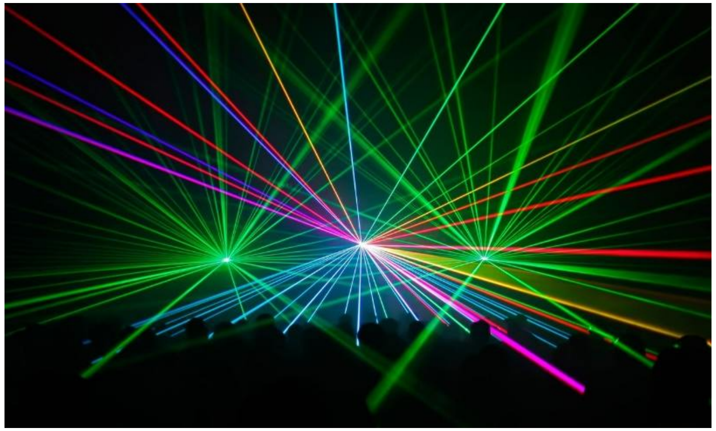
US studies attributed > **30 percent of US GDP** growth to quantum physics

Time: From 1900 to first applications took 40-50 years

4. Lasers

1917 Einstein formulated the important theoretical basis for lasers.

1928 first experimental proof of stimulated emission (Ladenburg)



1954 Charles Townes built first Maser

1960 Theodore Maiman built first functioning Laser, based on theory by Townes and Schawlow. (His report to Physical Review Letters was turned down, but accepted by Nature)

…"A solution looking for a problem"… (Ch. Townes)

Today, may types of lasers from gas to solid state are used nearly everywhere

Lasers Applications

Basic research

Applied sciences

Medicine

Measurements techniques

Commerce

Data storage and
transmission (CD Player, …)

Illumination (LED)

Entertainment

Time from idea -> observation -> application: 30y / 80y

5. Communication and life style

The "invention" of the WWW

WWW has changed our way of life in very many ways

Its **origin** is based on **two elements**,

- the existence of the **physical infrastructure** (data nets and data transmission)
- The **software concept** underlying the www: Information is stored **only in one place**, identified by a unique address

The concept was developed for the needs of **particle physics** at CERN when around the year 1995 the teams of scientists became so large that the **classical sharing of information (by copying)** was no longer efficient or doable.

II. A question of time: First Idea to Product

The time from a discovery to an application can therefore vary **from years to many decades**.

This is a **historic lesson** which needs to repeated constantly to society and politicians with these and other similar examples.

Normally **unexpected** discoveries take **longer** to reach the market, for example quantum physics.

However, under the pressure of the society we witness a **greater awareness and readiness** on the side of scientists, that applications should be kept in mind.

III. Education, Awareness and Imagination

University education must provide first a **deep understanding of one field of science** plus …

Curiosity and knowledge **beyond the own field** of education

Readiness to **work at the border between disciplines** (interdisciplinary work)

Readiness for **continued learning**

…resulting in …

Knowledge transfer through **minds** (persons) which have learned to think independently

Enhanced awareness that science might have **application** and **imagination** what these might be.

Searching for new University Structures

Is there a best way to foster interdisciplinary thinking?

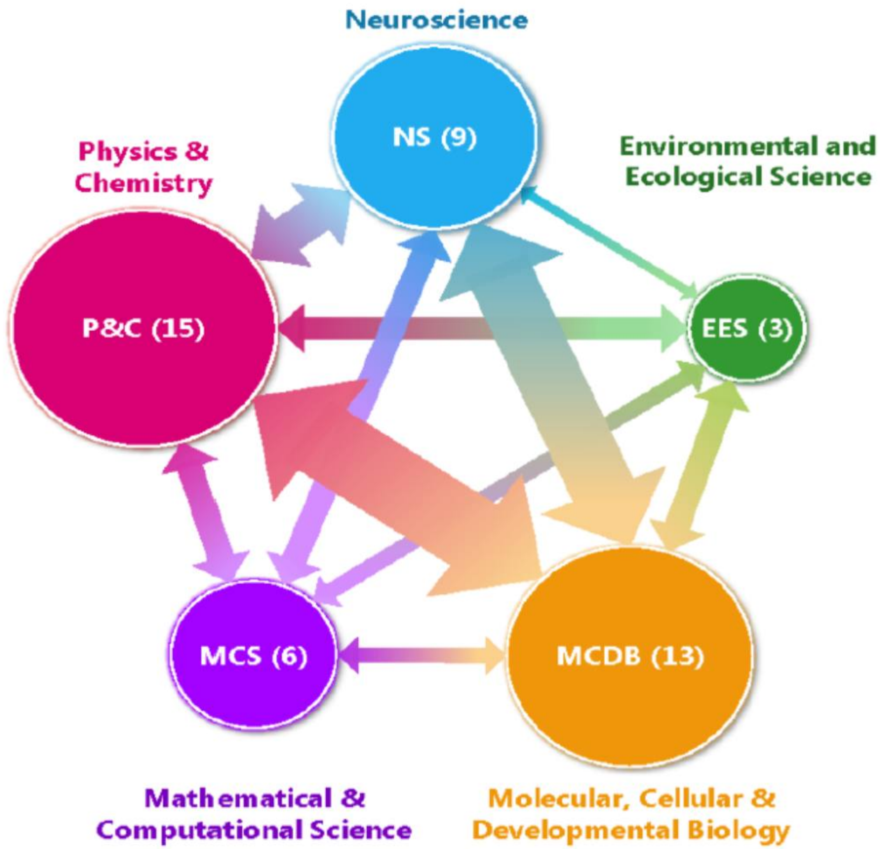
Example OIST:

No departments

Professors and students from different disciplines share the **same buildings**

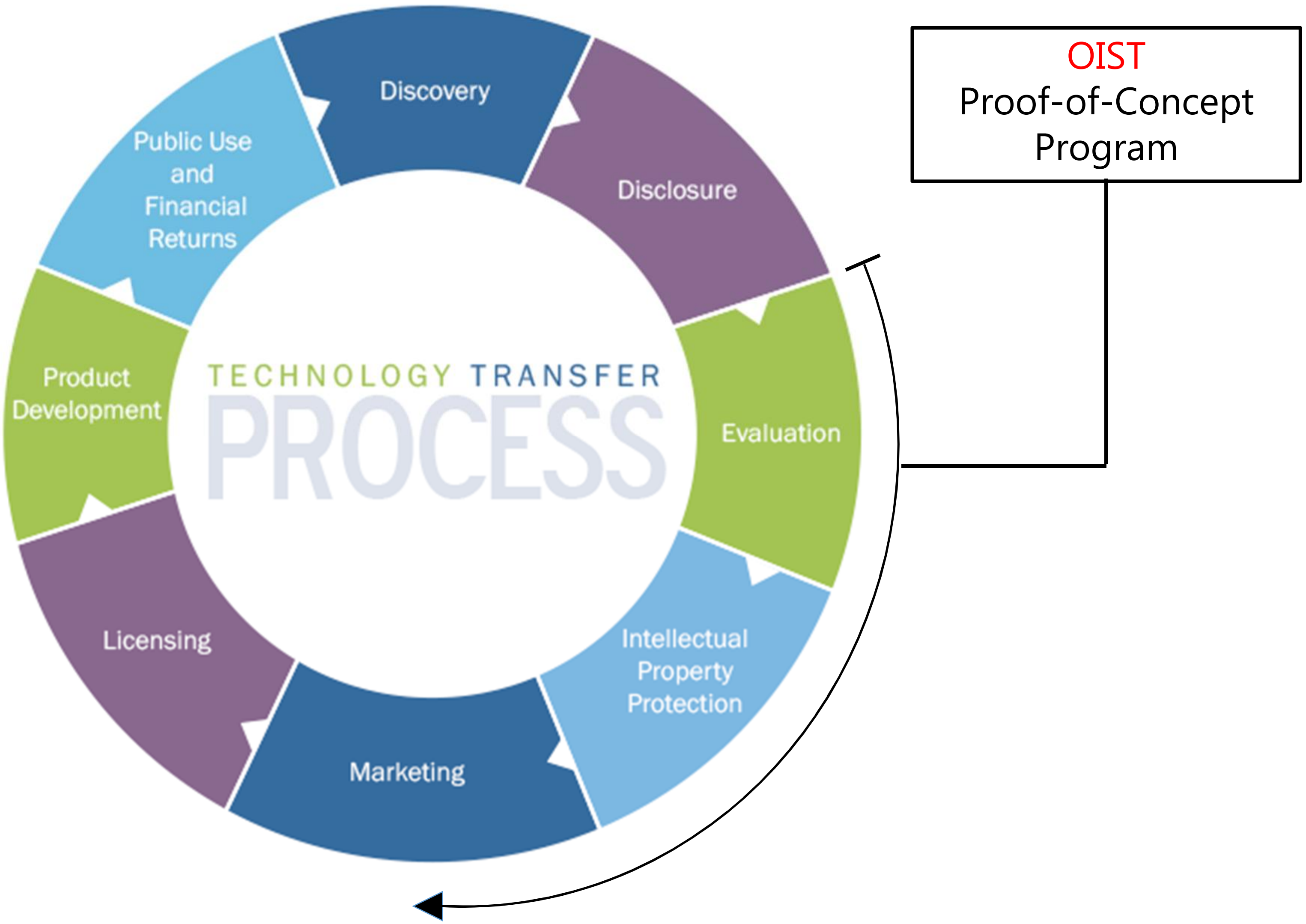
Graduate training includes rotation between three different fields of science

Research infrastructure is used jointly



Intensity of cross-disciplinary research interactions

IV. From Discovery to Application



Tools for helping the transition : e.g. Proof of Concept

- **Proof-of-Concept** for application of basic discoveries
- Originated ~2002 at MIT and UCSD
- "Gap funding" support to facilitate transfer between universities and companies
- Training, mentorship, industry links

Impact of POC on Number of Startups	Number of Universities (U.S.)
Increase in Startups	19
Stayed the Same	4
Decrease in Startups	6
Total Studied	29

* C.S. Hayter & A.N. Link (2015) On the Economic Impact of University Proof of Concept Centers. J. Technology Transfer, 40:178-183.

V. Conclusion for Science Funding and Decision Making

- **Major** discoveries were **neither predicted nor planned**.
- They **relied on** a high **quality** of education and research, a **critical approach** (wrong or new result).
- This **will continue to be true in future.**

However,

- **Awareness** and imagination for **possible applications** need fostering.
- Education and research at the **border of fields** need strengthening.
- Universities and industry need to **bridge the gap** between discoveries and a product.