Nanotechnology curriculum

V2 (post-pilot)

Experts in Nanotechnology Exploitation project

ing. Henk-Willem Veltkamp MSc

Co-funded by the
Erasmus+ Programme
of the European Union

Curriculum v2.0 a.k.a. post-pilot curriculum

After the pilot, an evaluation questionnaire was held. The results of this were used to improve the curriculum for the e-course. Generally speaking, the pilot was well accepted by the participants, so the curriculum had to be modified only slightly. This resulted in the current and last version of the curriculum. This curriculum is therefore discussed more in-depth. The total amount of hours is now 77.5 hours.

Module 1	**Introduction to nanotechnology innovation**
Possible lecturer:	Martin Bennink
Study load:	7.5 hours
Description of the module (knowledge):	
This module starts with a quick recap by providing a general introduction of the broad field of nanotechnology. This starts by introducing the nanometre as a length scale and the differences that occur on this scale with respect to the macroscale, by demonstrating the interdisciplinary nature of the field, and the history of the emergence of nanotechnology will be discussed. After this recap, the application areas in which nanotechnology will have, or already had, its impact will be discussed. Different types of products that are already in the marketplace today will be discussed by looking at the impact on the market. In the last part of the module, the products discussed will be used to discuss the different societal aspects that arise with the introduction of nanotechnology, including the potential risks.	
Learning outcomes (skills and competences):	
After following this module, the trainee (is able to): - Explain what a nanometre is and list a number of examples of objects on that scale. - Give examples of the different physical properties between nanoscale and macroscale materials and explain these. - Has a good sense of the size of various micro- and nano-objects - Describe the history of the development of nanotechnology. - Explain why nanotechnology is an enabling technology. - Explain the relation between nanotechnology and biology - Discuss the various applications that can be expected from nanotechnology - Discuss a number of societal issues that arise with nanotechnology, including the risks	
Course materials:	
- Assignment: What comes to your mind when you hear "nanotechnology". Write down 5 terms that you personally most relate with nanotechnology. - PowerPoint presentation: What is a nanometre (maybe with reference to "Scales of the Universe": http://htwins.net/scale2/, so they can get a feeling of how small a nanometre is) - Graphic (maybe interactive) which various objects along it indicating its size. - PowerPoint presentation: History of the development of nanotechnology - Text: Transcript of the 1969 talk of Richard Feynman - PowerPoint presentation: Nanotechnology and the living world - Assignment: Identify three nanotechnology-enabled products that are already on the market. - Discussion: discuss this with your peers. - PowerPoint presentation: Application areas of nanotechnology - PowerPoint presentation: Societal aspects of nanotechnology, risks and opportunities - YouTube video(s): Showcasing some of these societal impacts - Self-testing quiz	

Module 2	Nanomaterials
Possible lecturers:	Peter Schön (polymers) Guus Rijnders (inorganics) Rob Lammertink (colloids)
Study load:	10 hours

Description of the module (knowledge):

This module is one of the basic modules of the course. First, an introduction into atoms and molecules, and the interacting forces in play at the nanometre scale, like van-der-Waals and Lennard-Jones, will be given. This is essential knowledge in the upcoming items in this module.

Next, the module will introduce a variety of usable materials and nanomaterials to the participant. The materials discussed are:

- Macroscopic materials which can be shaped on nanometre level:
  - Polymers
  - Silicon
  - Semiconductor
- The other class of materials discussed are the nanomaterials. These are made with the building blocks of nanotechnology: atoms and molecules. Examples of these nanomaterials are:
  - Carbon-based structures (nanotubes/fullerenes/graphene)
  - Biomolecules
  - Colloids
  - Nanoparticles (metal, semiconductor, polymeric),
  - Nanocomposites (combination of nanoparticles with biomolecules in pharmaceutical applications),
  - Nanocoatings (antimicrobial, omniphobic, etc.).

Of all these materials, the properties, applications, and fabrication methods will be discussed. Some of these briefly because a more comprehensive module about these topics will follow.

Learning outcomes (skills and competences):

After following this module, the trainee (is able to):

- List a number of different materials and nanomaterials.
- Explain why some applications are bound to a certain group of (nano)materials.
- Think about other applications of these (nano)materials.
- Discuss about the fabrication methods involved in these (nano)materials.

Course materials:

- PowerPoint presentation: Overview of different (nano)materials
- Table: properties of different (nano)materials
- YouTube: silicon/semiconductors used in nanotechnology (Intel has a nice movie of how silicon wafers are made)
- Animation/graphic: carbon-based nanomaterials
- PowerPoint presentation: biomolecules in nanotechnology
- Assignment: Give the participants three scenario's in which a problem can be solved with a nanomaterial (i.e. nanocomposite, nanocoating, biomolecule) and let them write a short essay (max 300 words) of how they would use the material of their choice.
- Discussion: Participants discuss the chosen method with the other participants
- Self-testing quiz (maybe after every 1 or 2 items a short quiz of 3 questions?)

Module 3	Processes & fabrication
Possible lecturers:	Alexey Kovalgin (bottom-up) Jurriaan Huskens (top-down) Nano-particles (Ron Gil)
Study load:	10 hours

Description of the module (knowledge):

The second basics module focusses on the processes and fabrication steps in which the nanomaterials are formed or the materials are being shaped to useful nanostructures. The structure of this module contains three main components, the two distinct approaches in the development of nanostructures and/or nanomaterials: top-down processing and bottom-up fabrication. The third component is the synthesis/fabrication of nanoparticles.

In **top-down processing**, we will discuss the concepts of:

- Lithography (photolithography, electron beam lithography, multi-photon lithography, scanning probe lithography, laser interference lithography),
- Etching techniques (wet etching/plasma etching, isotropic/anisotropic/directional etching),
- Deposition techniques, e.g. for thin-films (sputtering, ALD, MBE, PLD, PVD, and different CVD techniques like PECVD, LPCVD, MOCVD),
- Wafer bonding (anodic, adhesive, eutectic, metallic layer, fusion)
- Imprint techniques (hot embossing, nano-imprint),
- Soft lithography/rapid prototyping techniques.

-These techniques will be coupled to examples in wide range of applications, like MEMS-based nanotechnology, memory storage devices, nanosieves, nanostructured omniphobic surfaces, and microfluïdic devices.

For **bottom-up fabrication** we will discuss:

- Introduction into nanochemistry,
- Self-assembly,
- Monolayer formation,
- Sol-gel reactions,
- Microcontact printing

Application examples in this component are self-assembled protein cages for drug delivery, functionalized surfaces, and monolithic structures.

The third component, **nanoparticles** is a category on its own. These particles can be made with both top-down processing techniques (size reducing techniques) as well as bottom-up fabrication techniques (self-assembly).

The variety of materials of which these nanoparticles are made is wide and covers materials like gold and other metals and oxides to polymers. A special group of nanoparticles are the quantum dots, which are made as a hybrid system. These techniques, materials and applications will be discussed and compared.

Learning outcomes (skills and competences):

After following this module, the trainee (is able to):

- Tell the difference between bottom-up and top-down techniques.
- Set up a basic process outline for the fabrication of certain nanostructures.
- Name applications of nanoparticles.
- Name various applications of the discussed nanostructures.

Course materials:
- PowerPoint presentation: Different top-down processing techniques. - PowerPoint presentation: Different bottom-up fabrication techniques. - Animation/YouTube movie: Principles of photolithography, etching, deposition, soft lithography, self-assembly, and surface functionalization. - Table: comparison different materials of which nanoparticles are made. - Table: comparison different nanoparticle fabrication techniques. - Text: example process flow - Assignment: designing a basic process flow for a certain structure (for example the one they discussed in module 2) - Self-testing quiz

Module 4	Characterization
Possible lecturers:	Kees Otto (Optical) Peter Schön (scannin probe and electron microscopies) Christian Blum (Spectroscopy techniques, fluorescence) Guus Rijnders (X-ray techniques)
Study load:	10 hours

Description of the module (knowledge):

The last module of the basics part discusses different characterization techniques for nanostructures. We will focus on the explanation and identification of the physical and instrumental principles of the techniques, including molecular and continuum (macroscopic) scale characterization of organic and inorganic materials and their application to specific questions. By the end of this course the students are able to estimate specific nanostructure materials and molecular properties from given examples and problems. Techniques that are discussed are:

- Optical tools (microscopy, nanoscopy, PALM, STORM, STED)
- Scanning probe techniques (STM, AFM, SNOM/NSOM, SERS, TERS)
- Electron microscopies (SEM, TEM)
- Spectroscopy techniques (UV-vis, CFM, TIRF, IR, Raman, MS, SIMS)
- X-ray techniques (EDX/EDS, XPS, XRD)
- Other (contact angle, ellipsometry)

Learning outcomes (skills and competences):

After following this module, the trainee (is able to):

- Describe the fundamentals of the covered techniques.
- Identify a suitable technique for a proposed problem.
- Tell the differences between the electron microscopy techniques.
- Tell the differences between the scanning probe techniques.
- List the limitations of the discussed techniques.

Course materials:

- Text: history and development of (optical) microscopy techniques.
- PowerPoint presentation: explanation of different optical techniques.
- PowerPoint presentation: explanation of different scanning probe techniques.
- PowerPoint presentation: explanation of different electron microscopy techniques.
- PowerPoint presentation: explanation of different spectroscopic techniques.
- PowerPoint presentation: explanation of different X-ray techniques.
- Animation/YouTube: working of scanning probe techniques
- Animation/YouTube: working of spectroscopic techniques
- Animation/YouTube: working of X-ray techniques
- Assignment: write down which methods can be used to characterize the material of the assignment in previous modules.
- Discussion: discuss with other participants why you have chosen these techniques.
- Self-testing quiz

Module 5	Nanobiotechnology & medical applications
Possible lecturers:	Mireille Claessens (Nanobio) Martin Benink (Nanobio) Severin le Gac (medical) Loes Segerink (medical)
Study load:	10 hours

Description of the module (knowledge):

This is the first module that completely focuses on applications of nanotechnology. These are the nanobio and medical applications, where the medical applications can be seen as a subgroup of nanobio applications. Discussed applications are working principles which are already in on the market. Examples are the bio-inspired nanostructured surfaces with superhydrophobic and/or antibacterial properties, devices with a particular nanosensing application for the early diagnostics of diseases (the lab-on-a-chip systems), devices which are used for research on artificial organs (the organ-on-a-chip systems), and the field of nanomedicine.
In this module again a device-directed approach is followed. Meaning that the whole process from designing to material selection to fabrication to characterization will be discussed.
Besides this, also the real-life application will be discussed. The main question we are going to answer here is "how is nanotechnology used in an everyday scenario".

Learning outcomes (skills and competences):

After following this module, the trainee (is able to):

- Translate technology to a medical application.
- Identify the restrictions of such devices.
- Identify the sectors where bio-inspired nanostructured surfaces are needed.
- Explain the basics of organ-on-a-chip devices and the fabrication of these systems.
- Design a basic device for a given problem.

Course materials:

- Interview/movie: an interview with a medical professional which uses lab-on-a-chip systems
- Movie: Nanopil movie
- PowerPoint: history and overview of different lab-on-a-chip systems
- PowerPoint: Different nanosensing methods (biological, chemical, electrical, optical, mechanical, etc.)
- YouTube/presentation: fundamentals of nanomedicine;
- Table: overview of different nanomedicine delivery methods;
- PowerPoint: background and fundamentals of bio-inspired nanostructured surfaces;
- YouTube: applications of these surfaces;
- Assignment: write short essay (max 500 words) about an application of organs-on-a-chip and how such device is made
- Peer reviewing: peer-review two or three essays of other participants based on a short guideline (for example 5 points which should come back in the essay)
- Self-testing quiz

Module 6	Energy
Possible lecturer:	Mark Huijben
Study load:	10 hours

Description of the module (knowledge):

This module describes the use of nanotechnology in the exciting, dynamic and fast-developing field of nano-energy, which joins nanoscience and nanotechnology with energy science. We cover the science and engineering of nanomaterials and nanodevices used in all forms of (renewable) energy harvesting, energy conversion, storage of (renewable) energy, and utilization.

In the **harvesting** part the following techniques are discussed:

- Organic and inorganic solar cells
- Blue energy
- MEMS-based energy harvesting

Energy **conversion**:

- Dye-sensitized solar cells
- Photocatalysis
- Water conversion
- Proton exchange membranes

And in the **storage** part:

- Fuel cells
- Batteries
- Polymeric supercapacitors

Utilization:

- Comparison between different solar cells
- Status quo of fuel cells

The same structure as in the last two application-based modules will be used, meaning that both the development and the application will be discussed.

Learning outcomes (skills and competences):

After following this module, the trainee (is able to):

- Understand the basics of the discussed techniques and applications.
- Identify possible applications a technique.

Course materials:

- Text: review of nano-energy
- PowerPoint: Solar cells
- PowerPoint: blue energy
- PowerPoint: MEMS and energy
- PowerPoint: basics of energy conversion and the application of nanotechnology in this field
- PowerPoint: How to store energy (in nanostructures)?
- PowerPoint: Comparison between different solar cells
- PowerPoint: Fuel cells and their development.
- Self-testing quiz

Module 7	Nano-electronics & nano-photonics
Possible lecturers:	Wilfred van der Wiel (nano-electronics) Michel de Jong (nano-electronics) Floris Zwanenburg (nano-electronics) Sonia Garcia-Blanco (nano-photonics) Herman Offerhaus (nano-photonics) LioniX BV company (nano-photonics)
Study load:	10 hours

Description of the module (knowledge):

This module describes hot and fast evolving field of nano-electronics and nano-photonics. However, these fields are more fundamentally than the previous covered topics, we would like to introduce you into these fields, since applications are expected in the near future. The module can be split into a nano-electronics part and nano-photonics part, both covering their own topics:

Nano-electronics:

- Introduction into nano-electronics (quantum behaviour of electrons), which quantum effects can give revolutionary electronics?
- CMOS scaling and its limits, Moore's law and beyond Moore (more Moore vs. More than Moore),
- Nanometre MOSFETs
- The quantum dots and wires and their applications (Single electron transistors, Coulomb blockade)
- Introduction into spintronics
- Magnetic properties of thin-films and its application in magnetic random access memory
- Magnetic nano-oscillators
- Organic electronics, Molecular devices, single molecule transistors
- Flexible electronics/polymer electronics
- MEMS/NEMS/MOEMS/NOEMS

Nano-photonics:

- Plasmonics
  - Volume plasmons, localized plasmons, and surface plasmons
  - Plasmonic waveguides
  - Size, shape, material dependence on the resonant behaviour of metallic nanoparticles
  - Applications of plasmonics
- Photonic crystals (banddiagram, photonic bandgap, real and reciprocal space, Bloch theorem, Brillouin and reduced Brillouin zone)
- Nano-optics in nanomicroscopy techniques (FRET, STORM/PALM, STED, NL-SIM)
- Nanosensing

Learning outcomes (skills and competences):

After following this module, the trainee (is able to):

- Describe in basic concepts the quantum effects important for nano-electronical and nano-optical devices.
- Discuss about the viability of the Beyond Moore devices like single molecule transistors.
- Explain in own words the basics of spintronics.
- Tell the difference between volume plasmons, localized plasmons, and surface plasmons.
- Has a rough understanding of photonic crystals, their underlying theory and their application as well

- Has a more detailed understanding of the applicability of the nanomicroscopy techniques discussed in module 4.
Course materials:
- YouTube movies explaining basic concepts - PowerPoint presentations explaining the concepts - Self-testing quiz

Module 8	**Case study**
Possible lecturers:	Martin Bennink (Nanotechnology part) …. (Innovation Management part)
Study load:	10 hours
Description of the module (knowledge):	
This is the closing module of the course, in which you will combine the knowledge of the Nanotechnology module and the Innovation Management module. The participant will be given a relevant problem for which a solution needs to be found. This solution has of course to be nanotechnology-based. Once the participants worked out his or her solution, a continuation into innovation management will done. Central questions in this part of the case study are "how do you protect your solution", "how will you divide your money stream", and "how will you market your solution". All the findings will be combined into a short report and submitted.	
Learning outcomes (skills and competences):	
After following this module, the trainee (is able to): - Look at a problem with a multi-disciplinary mind-set. - Think outside the box when a problem is given. - Starts already thinking about innovation management in the first stages of the solution finding process. - Combine nanotechnology know-how with innovation management processes into a report.	
Course materials:	
- Case study - All course material of previous modules - A standard report structure - Self-assessment form	

As can be seen, some changes are made with regard to the previous version (curriculum v2). First of all the first module is changed from **Introduction to nanotechnology** to **Introduction to nanotechnology innovation**. This stretches much more the goal of ENEX. Besides the nanotechnology introduction there will also be given an overview of nanotechnology innovation in the past and how different processes, like the technology readiness levels, work.

Also, the **Nanobio applications** and **Medical applications** modules are combined into one module: **Nanobiotechnology & medical applications**. This is done because this way an overlap in themes is prevented. Both modules showed a big connection with each other, so it was obvious to combine them.

Also, the content of the modules is completed. More different fabrication methods are added in the **Processes & fabrication** module, and the whole **Nano-electronics & nano-photonics** and **Case study** module are set up.

Presentations

The current state of progress is the development of the PowerPoint presentations with the real content. The approach for this is as follows. First the basic structure with all the slide titles is made by the curriculum developer. Then, together with the responsible lectures, the content is added. This decreases the workload for the responsible lectures. As example, the first version of the presentation for module 1 is given below.

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Module 1
Introduction to nanotechnology innovation

Martin Bennink

V0.1

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Menu

- What is Nanotechnology
- Science, technology and wealth
- Innovation
- Nanotechnology products
- Application areas

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Technical specification of nanotechnology

ISO (International Standards Organization) has set up a Technical Committee (TC 229) devoted to nanotechnologies

→ UNIQUE: It is the first time that we will have technical specifications in advance of a significant industrial sector.

→ It is an essential prerequisite for the formulation of manufacturing standards.

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Technical specification of nanotechnology

Scope:
Standardization in the field of nanotechnologies that includes either or both of the following:

1. **Understanding and control of matter and processes at the nanoscale**, typically, but not exclusively, below 100 nanometres in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications,
2. **Utilizing the properties of nanoscale materials** that differ from the properties of individual atoms, molecules, and bulk matter, to create improved materials, devices, and systems that exploit these new properties.

Specific tasks include developing standards for: terminology and nomenclature; metrology and instrumentation, including specifications for reference materials; test methodologies; modelling and simulations; and science-based health, safety, and environmental practices. Technical specification of nanotechnology

See: http://www.iso.org/iso/iso_technical_committee?commid=381983

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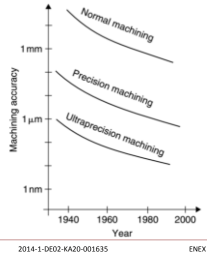
Nanotechnology as process

Nanotechnology is looking at things (measuring, describing, characterizing and quantifying)

But it also about MAKING THINGS



Norio Taniguchi (Univ of Tokyo) On the basic concept of 'Nano-Technology'

→ Nanotechnology must be the end-point of ultraprecision engineering (cannot get smoother than atomic roughness)

N. Taniguchi, "On the Basic Concept of 'Nano-Technology'," Proc. Intl. Conf. Prod. Eng. Tokyo, Part II, Japan Society of Precision Engineering, 1974

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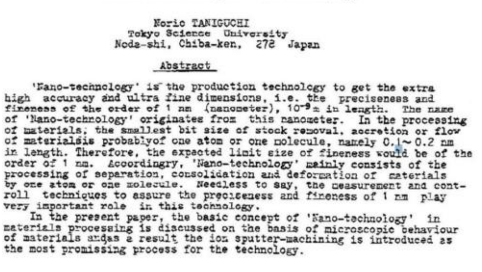
First paper mentioning nanotechnology



On the Basic Concept of 'Nano-Technology'

Norio TANIGUCHI
Tokyo Science University
Noda-shi, Chiba-ken, 278 Japan

Abstract

'Nano-technology' is the production technology to get the extra high accuracy and ultra fine dimensions, i.e. the preciseness and fineness of the order of 1 nm (nanometer), 10^{-9}m in length. The name of 'Nano-technology' originates from this nanometer. In the processing of materials, the smallest bit size of stock removal, accretion or flow of materialsis probablyof one atom or one molecule, namely 0.1~0.2 nm in length. Therefore, the expected limit size of fineness would be of the order of 1 nm. Accordingry, 'Nano-technology' mainly consists of the processing of separation, consolidation and deformation of materials by one atom or one molecule. Needless to say, the measurement and controll techniques to assure the preciseness and fineness of 1 nm play very important role in this technology.

In the present paper, the basic concept of 'Nano-technology' in materials processing is discussed on the basis of microscopic behaviour of materials andas a result the ion sputter-machining is introduced as the most promissing process for the technology.

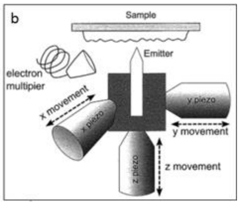
From: N. Taniguchi, "On the Basic Concept of 'Nano-Technology'," Proc. Intl. Conf. Prod. Eng. Tokyo, Part II, Japan Society of Precision Engineering, 1974

"Topografiner"

By scientists of the National Bureau of Standards, Washington, D. C. 20234 this instrument was constructed

→ Enabled to image topography

Led to development of STM, and then AFM

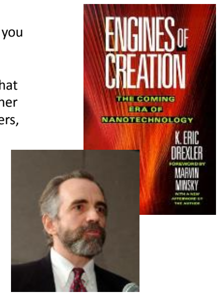


See: R. Young et al., The Topografiner: an instrument for measuring surface microtopography., Rev Sci Instrum 43, 999-1011 (1972)

Molecular manufacturing

"If you can position atom very atom one by one, you can build anything you want"

"As a next step you can build nano-assemblers, that are able to build nano-structures for you, and other assemblers, that can create these nano-assemblers, etc …"

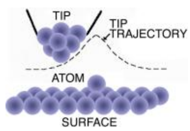


K. Eric Drexler

Molecular manufacturing

Applying current when STM tip is held in close contact can break atomic bonds

→ Enables manipulation



Xe atoms on a Ni surface (at 4K)

(took 24 hours to do it)

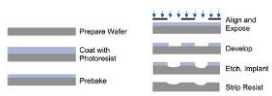
Source: IBM Research, Almaden (1990)

Molecular manufacturing

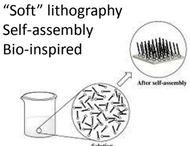
Further progress in realizing as assembler has been extremely slow

2 new manufacturing approaches appeared

Top-down
- Lithography
- Precision engineering



Bottom-up
- "Soft" lithography
- Self-assembly
- Bio-inspired



Nanotechnology as materials, devices and systems

As materials:
- Nanocoatings (1D)
- Nanorods, nanofibers, nanowires (2D)
- Nanoparticles (3D)

INCREASING COMPLEXITY

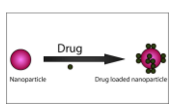
Materials → Devices → Systems

Devices: Nanoscale device = nanoscale automaton (responsive/smart nanomaterials)

Systems: System is not always clearly distinct from device

Direct, indirect and conceptual nanotechnology

Direct NT:
- Nanosized objects directly used in application



Indirect NT:
- Device that contains a nanodevice

Conceptual NT:
- Refers to considering systems, or phenomena from a nano viewpoint

Molecular medicine: attempt to understand diseases by the actions of molecules

(=NANOSCIENCE)

Definition nanotechnology

"The design, synthesis, characterization and application of materials, device, and systems, that have a functional organization in at least one dimension on the nanometer scale"

US Foresight Institute:
"Nanotechnology is a group of emerging technologies in which the structure of matter is controlled at the nanometer scale to produce novel materials and devices that have useful and unique properties"

Distinguishes it from chemistry

NOTE: within the definition, there is an emphasis on **novel** and **fundamentally new** properties and aspects.

Sorts of knowledge

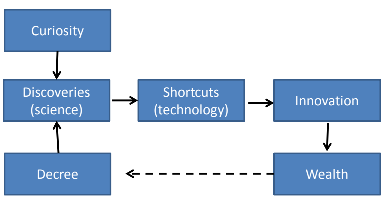
Unconditional knowledge:
- Reliable facts
- Knowledge does not depend on the experimenter

Conditional knowledge:
- **Inductive inferences** drawn from facts by creative leaps of human imagination.

Human inventions

Inductive knowledge is
- at the heart and soul of science
- The "real" addition

Linear model (science, technology, wealth)



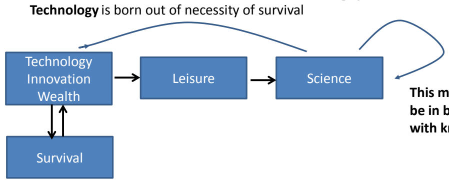
This model is still applied by many governments today

(in the past: for survival, or military supremacy, now: commercial monopoly)

From: Francis Bacon, The Advancement of Learning, 1605

Alternative model (science, technology, wealth)

Technology is born out of necessity of survival



This model appears to be in better concord with known facts

More wealth creates leisure that can be used for scientific contemplation.
Driven by curiosity and desire to enhance man's knowledge of his place in the universe → natural philosophy.
Some of it, might enhance technology → dotted line

Applied Nanotechnology, Jeremy Ramsden, 2nd edition, 2014

Technology leads to science

Technology leads to wealth, and science cannot exist without technology

Industrial Revolution → 1760 – 1820
(James Watt developed the steam engine from 1763 to 1775)

1824 → Nicolas Leonard Sadi Carnot published his work on thermodynamics. This later led to the development of the 2nd law of thermodynamics and concept of entropy (by Rudolf Clausius and Lord Kelvin)

1840 → James Prescott Joule discovered 1st law of thermodynamics

Started with technology and science followed later !!!

(Similar story for electricity, radio and others)

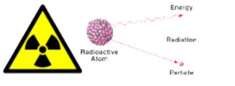
Applied Nanotechnology, Jeremy Ramsden, 2nd edition, 2014

But, early 20th century

Technology before science model worked up till the early 20th century

Discovery of radioactivity (1896 by Henri Becquerel) and atomic (nuclear) fission (1938)

1942 → first atomic pile/reactor
Later: nuclear bombs and electricity plants



Something changed:
- There was sufficient wealth accumulated
- Allowing science to be conducted

Applied Nanotechnology, Jeremy Ramsden, 2nd edition, 2014

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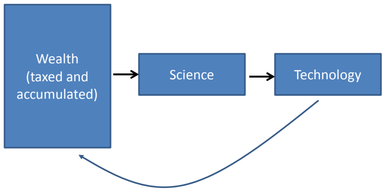
New model (also for NT)



Governments were (and are) still convinced that the linear model is at work, and therefore science received a lot of funding
→ (Nano)science was (and is) seen as the way to create more wealth

BUT NOTE: The relation between technology and wealth is not that clear.

Applied Nanotechnology, Jeremy Ramsden, 2nd edition, 2014

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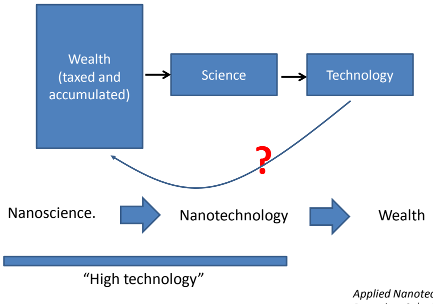
New model (also for NT)



Applied Nanotechnology, Jeremy Ramsden, 2nd edition, 2014

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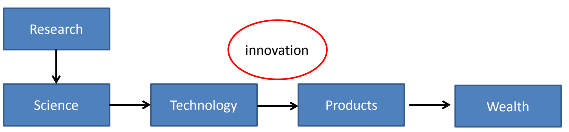
From science to wealth



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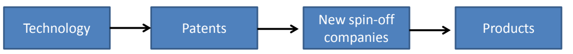
From technology to products (innovation)



Innovation = "the bringing in of novelties"

BUT nowadays this is charged with "animating economic activity"

Innovation = "process whereby new products are introduced into the commercial sphere"

Applied Nanotechnology, Jeremy Ramsden, 2nd edition, 2014

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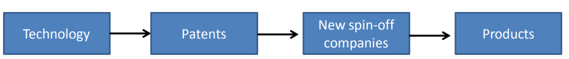
Technology push / Market pull



Technology push
(or technological imperative):
→ Disruptive innovation (market cannot demand something it does not know about)

Market pull
→ Incremental innovation (technology responds to customer feedback)

They need to be matched to have succesfull innovation

Exceptions to the rule:
- In case of monopoly incremental technology can be introduced without any market pull
- Latent demand can explain how disruptive technology can catch on fast.

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Innovation management

Average lifetime of company = 12 years
→ company need to remain agile (ability to adapt)
→ Good balance between exploration and incremental improvement (multiple activities)

More investment in R&D ➡ **More patents** ~~➡~~ **More corporate performance (sales)**

Other factors
- Public acceptance is important to consider
- "Habituation" → the market can be considered as a dynamical system with multiple minima. Once it is caught into one minimum it is difficult to escape from it.
- Interaction with society → adoption of artefacts produce lifestyle changes (value is not directly correlated with amount of functionality of a product)

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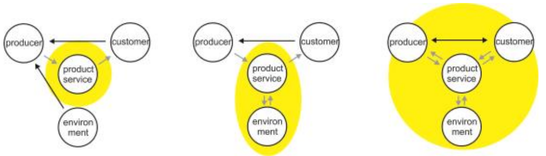
Value creation



Value provision: value for customer and producer can be specified independently, environment is fixed → search for optimal solution

Adaptive value: same as above but environment changes → requires adaptive strategy

Co-created value: value for customer and producer cannot be specified independent. Constant interaction between the two, cannot be separated

This applies to current innovation, including NT

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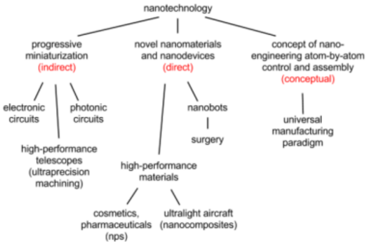
The nanotechnology business



Most prominent applications:
- Substitutional indirect technology (nanoscale lithography)
- Incremental quasi-direct technology (carriers for active ingredients in cosmetics)

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Size of NT market

There are many reports providing estimates of the size of the NT market,

BUT, it is not always clear if:
- It includes the total value of a product containing nanotechnology
- Items are double counted (due to badly defined sectors within the NT field
- Is "old" nanotechnology included

Old nanotechnology includes ($ $5{\cdot}10^9$ per year):
- Carbon black ($ $2.5{\cdot}10^9$) as additive for rubber in tires.
- Silver halides in photographic applications (this is reducing fast)
- Titanium dioxide as white pigment in paint.

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Current situation

Expected for 2015:

Global market of nanotechnology is about $27 10^9.

20 10^9 of this is in nanomaterials
7 10^9 of this is in nanotools
230 10^6 of this is in nanodevices

Size of the market is similar to the biotechnology sector, but far smaller than the global informatics market (3.6 10^{12}).

Numbers are predicted by the Economic Research Unit of the INSCX exchange on Aug 2, 2012)

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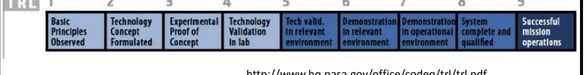
Technology readiness

Readiness of a technology is expressed in TRL = Technology Readiness Levels.

→ Introduced by NASA in 1995 (Stan Sadin, of NASA already in 1974 came up with the first TRL scale with 7 levels)

→ Tool to an index to measure the maturity and usability of an evolving technology.

→ Increasingly used for benchmarking, risk management, and funding decisions .



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http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

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TRL provides standard

Today's business is more chaotic than ever.

Many call it **VUCA**: Volatile, Uncertain, Complex, Ambiguous

Or even Super **VUCA**: Vibrant, Unreal, Crazy, Astounding

Characteristics:
- Values are not created by single entities (but networks)
- Traditional industry borders disappear
- No value relies on a single technology or resource.

TRL provides an independent standard

(note this: TRLs are describing the R&D process per se but the step by step making of an innovation enabled by R&D)

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Definition of TRL levels

TRL	DEFINITION
TRL 1	basic principles observed
TRL 2	technology concept formulated
TRL 3	experimental proof of concept
TRL 4	technology validated in lab
TRL 5	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6	technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7	system prototype demonstration in operational environment
TRL 8	system complete and qualified
TRL 9	actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

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What level is my project?

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TRL 1–3: Research in which commercialization is ignored

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Research-intensive innovative SMEs start from TRL 4 (originate innovative products above scientific explanation)

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R&D is pivotal

TRL 6 = transition from research + experiment to real-life implementation and commercialization

Assuring management confidence

individual technologies and stand-alone elements are not a matter of discussion any more

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How about nanotechnology

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NT is clearly distinguishable as separate entity

NT is part of a larger entity

NT is only a small part of a system (which is the product, service)

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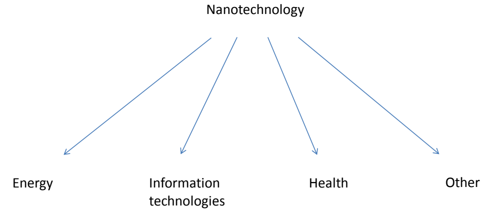
Application areas



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Energy

- Harvesting energy
  → Heat (skin), movement (compression under foot), chemical fuels (glucose, fat)
  → Exploit concentration gradients
- Production and storage
  → Novel PV (are expensive now) Novel storage media
  → New fuel cells (fuel conversion to electricity)
  → Supercapacitors (based on CNT)
  → H2 storage in new media
- Improving energy efficiencies of human activities
  → Nanostructured coatings with low friction
  → Light-weight materials
  → Localized manufacturing

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Information technologies

- Silicon microelectronics → Transistors will get smaller and smaller: (45 nm in 2009, 22 nm in 2015)
- Heat management → New thermal interface materials (carbon nanotubes)
- Data storage technologies → Use electron spin for magnetic memories
- Display technologies → New display technologies such as OLEDs
- Molecule or particle sensing technologies
  → Converting irradiance of certain wavelength of light or concentration of molecules to electrical signals
  → Nanosensors (very specific, and sensitive)

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Health (nanomedicine)

Nanomedicine is the application of nanotechnology to human health

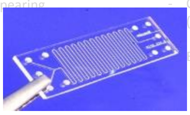
time →

- Laparoscopic diagnosis
- Surgery with microscale instruments
- Lab-on-a-chip

→ Is more 'micro' than 'nano'
→ Already quite established

- Nano-objects
- Other nanomaterials

→ Is very well researched
→ Commercial products just appearing



- Sensorization (small sensors that can penetrate into the body
  → continuous monitoring
- Automated diagnosis
- Customized drugs (personalized medicine)

→ Envisioned for future

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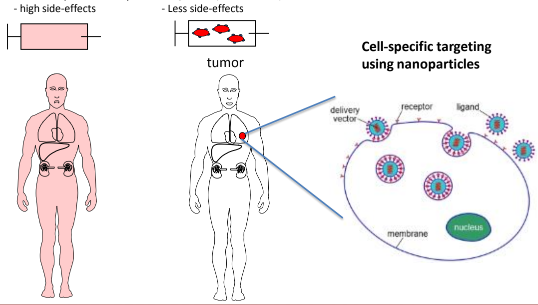
Health (nanomedicine)

Free drug
- low therapeutic efficacy
- high side-effects

Nanomedicine
- High therapeutic efficacy
- Less side-effects



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- Tissue scaffolds
- Structural implants (teeth)
- Implanted devices

- Sensorization (small sensors that can penetrate into the body

→ Envisioned for future

Health (nanomedicine)

Nanomedicine is the application of nanotechnology to human health

time →

- Laparoscopic ... objects
- Surgery with ... nanomaterials instruments
- Lab-on-a-ch... well researched ...ercial products

→ Is more 'mic... 'nano'
→ Already quit...

IBM Watson Health: System that can analyze unstructured data (for example to automate diagnosis of patients)

- Sensorization (small sensors that can penetrate into the body → continuous monitoring
- Automated diagnosis
- Customized drugs (personalized medicine)

→ Envisioned for future

Other application areas

- **Aerospace/automotive industries:**
  - reduce vehicle weight
  - conducting/ultrahard paint)
- **Architecture and construction** (low-tech environment → market penetration slow):
  - superhydrophobic glass
  - nps with TiO2 to absorb UV ligth to decompose pollutants
  - nanocoatings to control transparency
  - "anti-graffity" paint
- **Catalysis**
  - Catalysts can be engineered atomically precise, enhancing its activity
- **Environment** (very amorphous in the commercial sphere)
  - Remediation of contaminated soil or ground water
  - atomically precise and flexible manufacturing will eliminate waste and transport
- **Food**
  - enhanced materials for packaging
  - agriculture (by pervasive sensing and monitoring)
  - sensors to monitor food quality
  - nano-additives
  - enhancement of their functionality (functional food, nutroceuticals)

Other application areas

- **Lubricants**
  - novel low friction coatings (composites with nanoparticles?)
- **Metrology instrumentation** (
  (is a small market, sector must become more divers)
  - development of SEM, optical microscopy and EM
- **Minerals and metal extraction**
  - use biomimicry: some living organisms are extremely good at extracting directly raw materials
- **Paper industry**
  - use of nps to tag paper
  - coat cellulose fibers to create durable paper
- **Security**
  - light-weight materials and armor → advantage in battle
  - detection of explosives using nanosensors
- **Textiles**
  - nano-additives can enhance textile fibers (in enhancing strength, durability, flame resistant, self-cleaning, anti-septic, releasing chemicals)

Summary

- Nanotechnology is high-tech: science leads to technology, but NOT automatically to wealth
- Innovation is key here (technology push and market pull)
- Most value in nanotechnology can only be created in co-creation
- TRL levels are a good tool to get more grip on the readiness of a technology.
- Main application areas of nanotechnologies are energy, information technologies and health.

Thanks for your attention