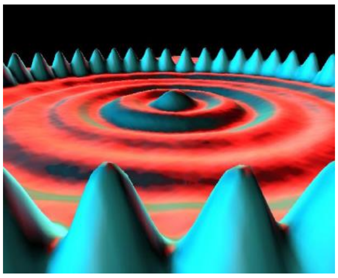
Bridge between research in modern physics
and entrepreneurship in nanotechnology

Teacher Guidelines

Version 1



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Lifelong Learning Programme

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1 Introduction

The *Quantum Spin-Off* project deals with the area of nanosciences. The teacher guidelines at hand were developed within an EU Comenius project. The project partners are from Belgium, Estonia, Greece, and Switzerland. Depending on interest and time available, only a selection of chapters may be considered.

1.1 Overview Quantum Spin-Off Project

First, the Quantum Spin-Off project is briefly presented from the students' perspective.

Project goal: Establishing contact between schools and researchers as well as companies in the area of nanosciences or nanotechnologies.

Class type: Classes in 10^{th} to 12^{th} grade with a scientific / technological focus or interested classes of the basic subjects of physics or chemistry.

Web address: The teacher guidelines can be downloaded from the following internet address: www.quantumspinoff.eu

Visits: The classes visit a nano-research laboratory and a nano-company. They get in direct contact with researchers and companies.

Quantum physics: The students prepare learning stations relating to quantum physics.

Scientific publications: The students exploit scientific publications in the area of nanosciences / nanotechnology, ideally relating to the research area of the research laboratories / nano-companies visited. They pose question to the researchers via e-mail or Skype.

Virtual spin-off company: Based on the research results presented in the publication studied, the students create a virtual spin-off company by means of a simple business plan.

Brochure and presentation: The students prepare a brochure as a basis for the presentation (20 min, 5 min questions).

1.2 Structuring of Chapters

All chapters are basically structured as follows:

1. Learning goal
2. Sequence
3. Contents
4. Didactical considerations
5. Activities for students and teacher
6. Exercises for teachers (education and training)

Announcing the *learning goals* leads to transparency for students and boosts the learning success. The *learning goals* can be formulated as competences (connecting aspect of action with subject area). The *sequence* chapter provides a suggestion as to when to deal with the respective topic in a learning unit. The topic is clarified in the chapter *contents*. The *didactic considerations* are introduced with a quotation regarding study results. In order to create a link between knowledge and action, *activities* for students and *exercises* for teachers in education and training are proposed.

2 Getting into the Nanoworld

2.1 Etymology of the Term *nano*

Learning goal: … explaining the term *nano*.

Sequence: Introduction [Unit 1]

Literature: *Kumar (2007) conducted an exploratory study of 109 Australian pre-service teachers' knowledge of nanotechnology. This study also found there was a lack of understanding of … the etymology of the term 'nano'.*

Teacher activities:
What does the word *nano* have to do with dwarves? As an introduction into the teaching sequence, the teacher explains the etymology (origin) of the term *nano*. The greek word *nanos* means dwarf, the prefix *nano* derives from *nanos*.

2.2 Understanding the Nanoscale

Learning goal: … developing a feeling for the nanoscale.

Sequence: Introduction [Unit 1]

Literature: *Kumar (2007) conducted an exploratory study of 109 Australian pre-service teachers' knowledge of nanotechnology. This study also found there was a lack of understanding of the underlying physical scale of nanoscience and nanotechnology, … If teachers lack a fundamental knowledge of the size and scale of nanometers, it is not clear how they can understand and teach students about how materials behave differently and how tools and techniques differ when working at this small scale.*

Contents:
The nanoworld is an abstract territory, as nano-objects are very small and the processes in the nano-area cannot be observed directly. There is no automatic feeling for the nano-dimension. The students can only develop a concept of the nano-dimension by means of special training. Haptic feedback when operating the microscope would be ideal to develop an idea of the nano-dimension. Another possibility in order to illustrate the nano-dimension are comparisons:

- How many times smaller is a nanometer than the diameter of a human hair? The human hair has a diameter of 0.1 mm. A nanometer is 10^5 (100'000) times smaller than the diameter of a hair. (1nm = 10^{-9} m = 0.000000001 m). A nanometer approximately corresponds to the size of three gold atoms.

The movie ***powers of 10*** (9 min, maybe only show second half of movie) can also be used to illustrate the nano-dimension. Link to the movie (in English): http://www.powersof10.com/film

Microscopes (AFM, STM, EM) are the window to the nanoworld. The use of microscopes enables the understanding (nanosciences) and use (nanotechnologies) of nanoscale phenomena.

Student activities: Develop your own idea to illustrate the nano-dimension. The idea has to be simple to be presented in class in 5 min.

Exercises for teachers (education and training): Which central question(s) or tasks can you ask the students in regard to the movie “Powers of Ten”? By answering the central question, the students should reach the following learning goal: … developing a feeling for the nano-dimension.

2.3 Nano in Everyday Life

Learning goal: … linking new knowledge (skills) to everyday life (constructivist learning theory)

Sequence:
Introduction [Unit 1] or teachers in education and training (Spin-up Day)

Literature: *We learn by constructing our own understandings based upon our experiences, which are unique and thereby make our understandings unique . New information that we receive is compared to what we know from our experiences: what we learn is affected by what we already know. We apply what we know to a new situation: if new information does not fit with what we know, we may have to adjust how we think about the initial information and find where misconceptions occurred. Elworthy (2004)*

Didactic considerations: Generally, the students do not have any experience with the “nanoworld” yet. At the beginning of the teaching sequence, nanotechnologies can be linked to the students’ everyday lives. This link to the adolescents’ daily lives helps create an interest in nanosciences and nanotechnology. This learning process is further supported if they can build on previous experience, if the newly acquired information can be compared and linked to existing knowledge.

Student activities:
Nano-products are shown in class. The students have to decide, which nano-characteristics the respective products possess.

- self-cleaning surfaces: e.g. skiing goggles, spray for mirrors, lotus leaf (also leaf of lady’s mantle *alchemilla*, nasturtium *tropaeolum*, water lettuce *pistia*, columbine *aquilegia* etc.)
- antimicrobial effect of nano-silver: e.g. clothes, silver coin in milk (in former times, people put silver coins into milk in order to prolong the shelf life of milk. The silver coin leads to a slower multiplication of bacteria.)
- improved material properties due to carbon nano-tubes: e.g. tennis racket, bicycle frame
- surface effect: e.g. a beetle’s iridescent wings, mother of pearl in a shell (e.g. abalone, *haliotis*), bottom side of a gecko’s feet

The following link (also in English) provides a game in which nano-items have to be looked for in a room:

http://www.swissnanocube.ch/nanorama/?L=3

Game *Nanorama-Loft*: You have to look for 42 products from everyday life which contain nano-material or have been produced by means of nanotechnology. There are tasks in a multiple choice format for each product. You have to choose the proper nano-characteristic of the product from three possibilities.

Homework for students: The students can bring along nano-products which they have found at home. Alternative: the teacher brings along the nano-products.

Link with information on nano-products in everyday life (German only):

http://www.swissnanocube.ch/anwendungen-produkte/

Exercises for teachers (education and training): According to the moderately constructivist learning theory, items from daily life are suitable as a starting point in class. The students can actively construct new knowledge based on existing experience with nano-products.

As a teacher, you develop a task / a short teaching sequence on nano-products which students know from their daily lives. During the training, you test the teaching sequence. The other participants provide you with feedback concerning the following criteria:

- mobilization of students
- link to everyday life
- originality of idea

3 Learning Stations: Quantum Physics – New Concepts to Understand the World

Learning goal: … explaining the unique material behavior in the nano-domain.

Sequence: 5 learning stations relating to quantum physics [Units 2 to 8]. Depending on the time available, a selection of learning stations can be made (e.g. learning station I with no. 1&2, learning station II, learning station III without electromagnetic fields, learning station IV with no. 1&2).

Contents:
A new type of physics is needed in order to understand the nanoworld. In class, nanosciences are linked with existing scientific concepts. The unique material behavior in the nano-domain is highlighted.

Student activities:
The students work with the 5 learning stations.

<u>PART 1: WHY QUANTUM PHYSICS?</u>

Learning station I: Unexplained phenomena?

Learning station II: What is light?

Learning station III: Light as waves: What sort of waves are they?

Learning station IV: Duality of waves and particles – Quanta of Quantum Fields

Learning station V: Explaining the emission spectrum of hydrogen with quantum mechanics

Science-related considerations: It is important to see that the individual learning stations start with phenomena that cannot be explained with traditional physics, e.g.:

- the double-slit experiment which makes the classic concept of path irrelevant, or
- the elements' discrete emission lines, which cannot be comprehended by means of the classic atom-model by Rutherford. As a result, a new perception of nature has become inevitable.

By means of learning station V (Belgium), the students can calculate the frequency of the observed wavelengths of the hydrogen emission spectrum (with an accuracy of more than three digits after the decimal point!) by means of the quantum model by French physicist *Louis De Broglie*. *De Broglie* was inspired by musical harmonies, and this idea was used as a didactic analogon for learning station V. For some students, this last learning station V may be rather difficult. But if they master it, they can experience how a scientific theory can be drawn on to explain (part of) the world.

If enough time is available, the students work with the 5 learning stations of part 3, whereby they experience some quantum phenomena and properties of light by means of *hands-on* experiments.

<u>PART 3: HANDS-ON ACTIVITIES</u>

1. Discrete emission spectrum of chemical elements
2. Measuring the Planck constant by means of LED
3. Light diffraction using a hair
4. Electron diffraction using a carbon crystal

Laboratory work: The appendix includes task sheets (including solutions) regarding laboratory work.

Exercises for teachers (education and training): What constitutes the advantages of the methodic-didactic concept to work on a topic by means of learning stations? What is the teacher's role while the students are working with learning stations in class?

4 Learning Stations Relating to Nanotechnology

Learning goal: … practical implementation of quantum concepts in technologies.

Sequence: [Units 9-10]

Learning stations relating to technology, based on quantum-mechanical properties. In case of time constraints, a selection of the following learning stations has to be made.

Contents:
Nanotechnology: technology is a means of humans to design their environment according to their needs. *Nanotechnology* is applied in the areas of biomedical science (e.g. diagnostics, medical dispensing), nano-electronics (e.g. small transistors), and new materials (e.g. nano-based materials which are strong and light, or super-hydrophobic surfaces).

Nano-research: The success of *natural sciences* is based on the fact that consistent explanations which enable predictions can be created by means of scientific theories which can be tested on phenomena. Scientific laws describe formal connections between observable phenomena. *Nanosciences (nano-research)* are conceived as interdisciplinary studies (physics, chemistry, biology, and materials science) regarding objects of nano-dimensions.

Interdisciplinarity: Interdisziplinarity is intrinsic to nanosciences and nanotechnology. Nano-researchers and nano-technologists work closely together to ensure scientific progress.

The Quantum Spin-off project is designed in an interdisciplinary way:

- nanoscience (scientific papers & patents regarding interdisciplinary studies)
- nanotechnology (implementing research results in the form of technology)
- economic aspects when founding a virtual nano-company (*The Business Model Canvas*)

Student activities: the students work with selected learning stations of part 2: quantum properties and quantum technology

Part 2: QUANTUM PROPERTIES & QUANTUM TECHNOLOGY

Learning station VI: photo-electric effect and its application

Learning station VII: spin and its applications

Learning station VIII: semiconductor

Learning station IX: tunneling

Learning station X: quantum technology nanolab (e.g. Switzerland: University of Basel and Nanosurf AG in Liestal)

The learning stations of part 2 clarify how the quantum concepts in nature dealt with in the first five learning stations of part 1 – which, at first glance, seem rather philosophical– are practically applied in "everyday" technologies. Without our new findings in the area of quantum physics, there would not be any electronics, solar cells, MRI-scanner, or nano-surfaces. Thus, the new perspective on nature is at the core of almost all modern (sustainable) technologies . Even life itself (e.g. photosynthesis) is based on the quantum interactions between light and matter. As a result, what started as a special case of *physics of small things* can actually be found at the core of everything.

The learning station X regarding quantum technology was individually designed by the project partners of the four involved countries (Belgium, Estonia, Greece, Switzerland) and adapted to the research area of the institutions involved.

5 Publications in the Area of Nanocience

5.1 Selection of Publications

Goal: The scientific publications are selected in a way that dissolves gender-stereotypical division lines.

Sequence: Work with publications [Units 11-14]

Literature: There is a country-specific selection of scientific publications.

Contents:
Girls and women are interested in new technologies if they recognize them as a benefit for society.

Girls are particularly interested in interdisciplinary topics:

- electronics in the health sector
- biomedical applications, such as medical dispensing or diagnostics
- energy-saving technologies, such as solar cells

Ideally, the students are provided with the original English publication along with a popularized publication in their mother tongue which deals with the same topic. Thus, the language barrier is lower and specialist contents are provided according to the students' levels.

5.2 Reading Method

Learning goal: … applying the *SQ3R*-reading method.

Sequence: Reading the scientific publication

Student activities when applying the SQ3R-method

Survey: Get an overview over the entire text, read the respective headings and study illustrations & tables with captions

Question: Formulate headings as questions

Read: While reading the text:
- highlight important keywords and sentences in color (if needed, work with several colors)
- translate English words that are not clear by means of a dictionary
- clarify technical terms with the help of the teacher/internet/researchers
- ask your teacher or the researchers any content-related questions

Recite: draw conclusion (e.g. in note form, by means of mind-maps or concept-maps)

Review:
- Think of possible applications of the research results
- **Brainstorming**: How could the research results be used in a virtual nano-company?

Finally:
- Summarize the publication in three core statements
- Possibly present core statements to a group member

6 Nano-Companies – *The Business Model Canvas*

Learning goal: … founding a virtual nano-company.

Research results from the publication are utilized if a virtual nano-company is founded.

Sequence: *The Business Model Canvas* [Units 15-16]

Contents:
Introduction: Founding history, f.e. Nanosurf AG in Liestal (Switzerland). The story is about three physics students who built an international company on the basis of their work in nano-research.

The two following links provide an animated two-minute explanation of the *Business Model Canvas*.

http://www.businessmodelgeneration.com/canvas

http://www.youtube.com/watch?v=VfqEhQRMG1s

A business model comprises the following components:

- Producers (key partners, key activities, key resources)
- Product
- Customers (customer relationships, customer segments, distribution channels)
- Costs and returns

Student activities: Brainstorming regarding *The Business Model Canvas*

- How can research results from the publication be used in form of a technology?
- How can a company market the new technology? Answer the question by means of the business model (*The Business Model Canvas)*.

The *The Business Model Canvas* template can be enlarged onto a sheet of paper in A3-format . The students write their ideas directly under the individual components (handwritten, sticking on drawings or post-its).

Exercises for teachers (education and training):
Which methods are there to facilitate the brainstorming regarding the *Business Model Canvas*? Make concrete suggestions.

7 Establishing Contact of School Classes with Nano-Researchers as well as Nano-Companies

Learning goal: … establishing contact with nano-researchers and nano-companies.

Sequence: Visit nano-laboratory and nano-company (spin-up day, spin-off day and/or separate dates for visits)

Literature: *Falloon (2013) argues that achieving the theorised position of a shared partnership space at the intersection of the worlds of scientists and teachers is problematic, and that scientists must instead be prepared to penetrate deeply into the world of the classroom when undertaking any such interactions.*
Findings indicate epistemological differences, curriculum and school systems and issues, and teacher efficacy and science knowledge significantly affect the process of partnership formation.

In order to achieve a learning success by visiting out-of-school learning sites (e.g. nano-lab, nano-company), the trip has to be prepared and reviewed in class. How can visiting a nano-lab/nano-company be embedded in the *Quantum Spin-Off* project?

- work on learning station X? (practical application of quantum concepts in technologies),
- students prepare questions to be posed to the nano-researchers and
- after the visit, students stay in contact with researchers and companies via e-mail (students ask questions regarding the scientific publication and the transfer of research results into a virtual spin-off company)

Student activities:

Questions to introduce the researcher to the class:

- Could you tell us something about your career and your work here in the nano-lab?
- What fascinates you about nano-sciences?
- Why are you taking part in the "Quantum Spin-Off" project?
- At the end of the visit: How have you experienced the students' visit to the nano-lab?

Questions regarding the students' perspective:

- What are your expectations at the start of the visit to the nano-lab?
- Which questions do you want to ask the nano-researcher?
- At the end of the visit: What have you learned today about the work of nano-researchers?

Exercises for teachers (education and training): regarding visits to out-of-school learning sites such as nano-labs and nano companies

How can teachers mediate between the students' perspective and the researchers' perspective?

Literature: *Firstly, there must be consistency, agreement, and understanding of the pedagogical model underpinning partnerships and that these models should align with contemporary learning theories that acknowledge the agency and contribution of students. Secondly, scientist should be prepared to work exclusively within the limitations and constraints of teachers and schools. Thirdly, it needs to be accepted that partnerships are most likely not going to yield any significant benefits for scientists' work and that interactions are more likely to resemble outreach initiatives. (Falloon 2013)*

Guidelines for establishing contact with nano-researchers and nano-companies:

Look for nano-research labs or nano-companies, if possible in the vicinity of the school (see separate contact list of the countries involved in the *Quantum Spin-Off* project)

Teacher establishes first contact: The researchers and entrepreneurs must be put in the picture about the students' learning conditions and requirements. This includes the students' previous technical knowledge and the possibilities of how to connect to the students' everyday lives during their visit. A physicist talks about his/her CV and his/her fascination with the subject area of nanosciences. An entrepreneur relates the founding history of his/her company. Moreover, he/she defines the characteristics of a successful company.

Prepare visit: Program, goal (insights into nano-lab & nano-company), students may prepare their own questions to ask researchers or entrepreneurs.

Visit: Ideally, the students get actively involved during the visit:

- ask/answer questions: e.g. regarding items they discover in the research lab
- conduct their own experiment or document demonstration experiment
- take notes of short presentation

- document visit with their own photos (if taking photos is allowed) and comments

From the researchers' and entrepreneurs' view, the contact with schools primarily serves the promotion of young researchers.

Post-visit contact with researchers: How can number and style of e-mails be controlled in order to enable an appropriate communication between students and researchers? How can the teacher influence the e-mail communication between researchers and students so that the students do not send too many or too few e-mails?

- Specify a range for the proper amount of e-mails (according to experience, the students write rather few e-mails to the researchers).
- Discuss proper greetings, closings and phrases of expressing gratitude with the students.
- Document communication with researchers in the appendix of the brochure to be designed (e.g. list questions and answers)

Apart from e-mails, researchers and students can also communicate via Skype or the contact can be arranged by the researcher visiting the school.

The Business Model Canvas after visiting the nano-company: As an example, *The Business Model Canvas* sample plan can be filled in during the visit of the nano-company and with the help of an entrepreneur. (see Chapter 6: Nano-Companies – *The Business Model Canvas*)

8 Brochure and Presentation

Learning goal: Create a brochure and a presentation for the spin-off day [Unit 17-18 and as homework].

Brochure: The teacher can adjust the required length of the brochure to the time available.

A possible table of contents for the *Quantum Spin-Off project* brochure

1. Introduction
2. Research results from publication
3. Technological implementation of research results
4. Founding a spin-off company
5. Statement regarding the transfer of research results into a spin-off company (e.g. impact on society, "a look ahead", consideration of benefits and risks)
6. Appendix: documentation of questions to researchers and the respective answers

Assessment criteria for the brochure: technical accuracy, comprehensibility, completeness, design/layout

Presentation: e.g. with a Power Point presentation

Time per group: e.g. 20 min, 5 min questions

Contents: see 'brochure'

Assessment criteria: technical accuracy, performance, use of media, answering questions (probably modify assessment criteria)

9 Review

Learning goal: review

Sequence: Wrap-up [Unit 18]

Question:

What have you learned from taking part in the "Quantum Spin-Off" project?

Answer the question orally, as a flashlight question, or in writing.

Appendix

A Literature

Elworthy, A. (2004). Constructivist theory of learning. *Interaction, 18*(2), 28.

Fallon, G. (2013). Forging school-scientist partnerships: A case of easier said than done? *Journal of Science Education Technology 22*(2), 858-876.

Jones, M.G. et al. (2013). Nanotechnology and Nanoscale Science: Educational challenges. *International Journal of Science Education, 35*(9), 1490-1512.

Kumar, D.D. (2007). Nanoscale science and technology in teaching. *Australian journal of Education in Chemistry, 68,* 20-22.

B Laboratory work

Possibly include task sheets regarding laboratory work

C ICT-Tools

The following websites provide ICT-tools which support the students' learning process:

www.swissnanocube.ch (platform for nanotechnology and education, also in English)

www.youtube.com/watch?v=hAGP2sayis0 (experiment: graphene and batteries, graphene sheets and adhesive strips)

Possibly include further links

D Contact Data Nano-Companies and Nano-Labs

Include link of project partners (Belgium, Estonia, Greek, Switzerland)