Connecting **schools** with **high-tech research** and **entrepreneuship**

Bridge between research in modern physics
and entrepreneurship in nanoscience

Teacher Guidelines

Version 2

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Lifelong
Learning
Programme

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Table of Contents

1 Introduction

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.

The *Quantum Spin-Off* project deals with the area of nanoscience and nanotechnology. Nanotechnology is generally regarded as one of the key technologies of this century.

Quantum Spin-Off opens the world of modern physics to secondary school students. It shows the applications of quantum physics and gives them a taste of entrepreneurship for the high-tech sector. The high school students are brought in contact with research institutions in nanoscience and with high-tech companies (see appendix, part C). The students first develop some basic understanding of quantum physics and its applications by inquiry based methods. Later on, they work on the valorization of a specific idea in close collaboration with the researchers of the participating companies and institutions.

In the second phase of the project, the students start to think of a product or service as an application of the topic within modern science that they have learnt about. Finally they develop a business plan for their own spin-off company with the support of real businessmen.

1.1 Overview Quantum Spin-Off Project

First, we present the Quantum Spin-Off project trajectory and goals.

Project goal:

- Exploring quantum physics
- Linking school to high-tech research
- Fostering entrepreneurship in the science classroom

The primary focus, exploring quantum physics, is based on 12 learning stations and hands-on activities about inquiry-based and exploratory learning on phenomena and concepts of modern physics, especially of quantum physics and nanoscience.

The second key objective of the Quantum Spin-Off project is to establish contact between schools and researchers as well as companies in the area of nanoscience and nanotechnologies.

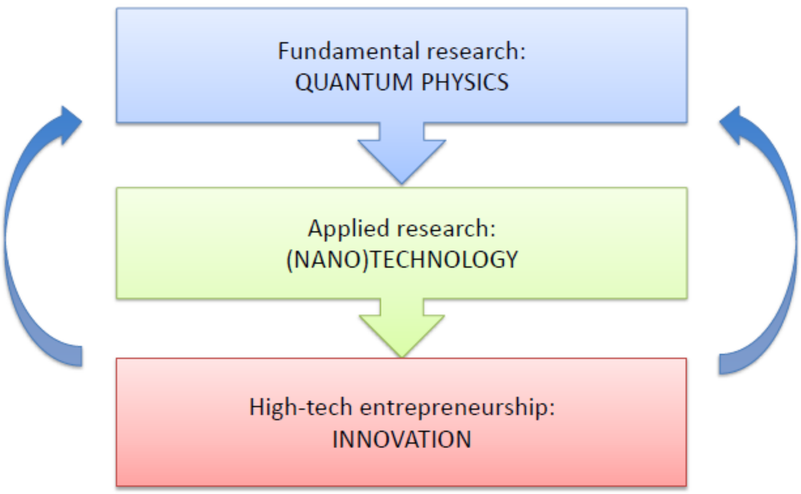

Figure 1 The Quantum Spin-Off philosophy

Furthermore the students participating in this project will experience that *interdisciplinarity* is intrinsic to nanoscience and nanotechnology. Nano-researchers and nano-technologists work closely together to ensure scientific progress.

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 work on learning stations relating to quantum physics.

Scientific publications: The students exploit scientific publications in the area of nanoscience / 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 (15 min, 5 min questions).

We wish all teachers and students joy and success in your work with this material.

1.2 Structure 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): https://youtu.be/0fKBhvDjuy0.

Microscopes (for STM see learning station VIII, for AFM see learning station X) are the window to the nanoworld. The use of microscopes enables the understanding (nanoscience) 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 nanoscience 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

The material is divided into 12 learning stations. Overview:

- I-V Quantum Physics (see this chapter 3)
- VI-XII Bridge to Technology (see chapter 4)
- Hands-on Experiments (see this chapter 3)
- The Business Model Canvas (entrepreneurship, see chapter 6)
- Teacher Guidelines with country-specific appendix (see this document)

The learning stations focus on substantive understanding, emphasizing self-activity and visualization. Hands-on experiments challenge students for active learning.

In this chapter we focus on the learning stations related to quantum physics (I-V) and the related hands-on Experiments.

Learning goal: … students gain a substantial overview of phenomena and concepts of quantum physics and the related technologies.

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, nanoscience 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 – part 1 - that can be complemented by hands-on activities - part 3.

PART 1: WHY QUANTUM PHYSICS?

Learning station I: Inexplicable phenomena with classical physics?

Learning station II: What is light?

Learning station III: What oscillates with light?

Learning station IV: Wave particle duality – Quanta of Quantum Fields

Learning station V: Predicting hydrogen emission lines with a quantum model

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, the students can calculate the frequency of the observed wave lengths 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 four learning stations of part 3, whereby they experience some quantum phenomena and properties of light by means of *hands-on* experiments.

PART 3: HANDS-ON ACTIVITIES

Discrete emission lines of chemical elements

Measuring Plank’s Constant with LED’s

Diffraction of light at a hair

Electron diffraction at carbon crystal

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. *Nanoscience (nano-research)* are conceived as interdisciplinary studies (physics, chemistry, biology, and materials science) regarding objects of nano-dimensions.

Interdisciplinarity: Interdisciplinarity is intrinsic to nanoscience 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

<u>Part 2: QUANTUM PROPERTIES & QUANTUM TECHNOLOGY</u>

Learning station VI: From photo-electric effect to digital imaging

Learning station VII: Semi conductors

Learning station VIII: Tunneling & STM

Learning station IX: Spin and its applications

Learning station X: Atomic Force Microscopy

Learning station XI: From quantum mechanics to nanoparticles and their applications

Learning station XII: Micro-sized microbial fuel cells

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 stations VI to XII, regarding quantum technology, were individually designed by the project partners of the four involved countries and adapted to the research area of the institutions involved.

5 Publications in the Area of Nanoscience

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.

For *The Business Model Canvas* learning resources, go to the project website:

http://qs-project.ea.gr/en/content/business-model

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 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 the learning station of part 2 (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:
<u>Questions to introduce the researcher to the class:</u>

- 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?

<u>Questions regarding the students’ perspective:</u>

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

<u>Teacher establishes first contact:</u> 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 nanoscience. An entrepreneur relates the founding history of his/her company. Moreover, he/she defines the characteristics of a successful company.

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

<u>Visit:</u> 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.

<u>Post-visit contact with researchers:</u> 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.

<u>*The Business Model Canvas* after visiting the nano-company:</u> 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 (aim of the project)
2. From modern science to technology (research results from publication, technological implementation of research results)
3. From application to business (founding a spin-off company)
4. 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)
5. Appendix: documentation of questions to researchers and the respective answers

Assessment criteria for the brochure: creativity, 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 for the presentation: 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.

10 How to use the learning stations

The aim of the project is to show to the students the connection between nanoscience and entrepreneurship. Therefore we suggest a possible learning line on how to use the learning stations in the class. Not all learning stations have to be used: The teacher can make a selection from the learning stations. It is also possible to start with a learning station from part 2 “technology”. However some learning stations are indicated as “recommended” in order to fully understand the underlying physics. The teacher should not leave the students on their own for the whole time they are working at the learning stations. In order to enable the students to understand the task, the teachers should provide some scaffolding. It is recommended to change didactic methods. The table below indicates the estimated time needed for each learning station.

Legend: r = recommended, e = elective

PART 1: WHY QUANTUM PHYSICS?	Estimated time: min	r/e
Learning station I: Inexplicable phenomena with classical physics?	45	r
Learning station II: What is light?	45	r
Learning station III: What oscillates with light?	45	r
Learning station IV: Wave Particle Duality– Quanta of Quantum Fields	45	r
Learning station V: Predicting the hydrogen emission lines with a quantum model	45	r*
Part 2: QUANTUM PROPERTIES & TECHNOLOGY	--	--
Learning station VI: From photo-electric effect to digital imaging	30	e
Learning station VII: Semiconductors	45	r
Learning station VIII: Tunneling & STM	30	e
Learning station IX: Spin and its applications	30	e
Learning station X: Atomic Force Microscopy	30	e
Learning station XI: From quantum mechanics to nanoparticles and their applications	30	e
Learning station XII: Micro-sized microbial fuel cells	30	e
Part 3: HANDS-ON ACTIVITIES	--	--
Discrete emission lines of chemical elements	30	r
Measuring Plank’s Constant with LED’s	30	r

Diffraction of light at a hair	30	r
Electron diffraction at carbon crystal	30	r

Learning station V: recommended up to section 4 and section 6. Section 5 “Calculation with the quantum atomic model” is elective.

Designing a learning path

Before the teachers start with the project, they design a learning path that fits to their class requirements. The teacher can use the following questions in order to prepare the course of the lessons:

1. Introduction of the project to the students: How will you start, what are the connections to everyday life?
2. Which class? How many hours per week? Which lessons? It is recommended that you choose a class that perhaps has additional weekly lessons in Physics.
3. How would you use the learning stations?
4. Which learning stations? Would you change them somehow? Would you include additional hands-on experiments?
5. Would you organize a competition? (at the class/school level/national level; to find other teachers you may contact the national project coordinator)
6. Scientific paper: How to look for one? Which type? Would you choose for it or would you let the students choose?
7. Would you give just one subject to the whole class and let students be responsible for different tasks? Or would you divide the class in subgroups with different subjects?
8. Would you organize a visit to a company? Which company and how would you find an appropriate one?
9. Would you work with a researcher?
10. Would you work with another teacher, e.g. Economics, English (and use the learning stations in English)?
11. How would you use the website?
12. Which type and extent of end work would you ask of the students? Presentation, booklet, report, exhibition…?

Appendix

A Literature

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

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

Recommended reading:

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

B References of scientific papers that students could use

Belgium

Optical techniques applied to ear research

- Muyshondt, P., De Greef, D., Soons, J., and Dirckx, J. (2014). Optical techniques as validation tools for finite element modeling of biomechanical structures, demonstrated in bird ear research. *AIP Conf. Proc., 1600*, 330.

Computed Tomography and sciagraphy

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Printable organic polymer solar cells

- Krebs, F.C. (2009). Fabrication and processing of polymer solar cells: A review of printing and coating techniques. *Solar Energy Materials & Solar Cells, 93,* 394-412.
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WOLEDs white organic light emitting diodes

- Kamtekar, K.T., Monkman, A.P., Bryce, M.R. (2010). Recent Advances in White Organic Light-Emitting Materials and Devices (WOLEDs). *Advanced Materials, 22,* 572-582.
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Estonia

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- Yang, C. et al. (2004). The application of recombinant human collagen in tissue engineering. *BioDrugs 18,* 103–119.

Artificial muscle wristwatch

- Carter, S. Haines et al (2014). Artificial Muscles from Fishing Line and Sewing Thread. *Science 343,* 868.

Nanoparticles and ionic liquids as oil additives

- Minami, I. (2009). Ionic Liquids in Tribology. *Molecules 14,* 2286-2305.

Wastewater fuel cell

- Mink, J. E., Qaisi, R, M., Logan, B. E., Hussain M. M., (2014). Energy harvesting from organic liquids in micro-sized microbial fuel cells. *NPG Asia Materials 6*, e89

Thorium as a source of nuclear energy

- Topf, A., (2014). Thorium: Energy Savior or Red Herring? http://oilprice.com/Energy/Energy-General/Thorium-Energy-Savior-or-Red-Herring.html

Nanosprings that produce electricity

- Vlassov, S., Polyakov, B., Dorogin, L. M., et al. (2014). Shape Restoration Effect in Ag−SiO2 Core−Shell Nanowires. *Nano Letters 14 (9),* pp 5201–5205.

Greece

- Stefi A.L., Sarantopoulou E., Kollia Z., Spyropoylos-Antonakakis N., Bourkoula A., Petrou P.S. et al. (2015). Nanothermodynamics mediates drug delivery. *Adv Exp Med Biol.*, 822, 213–30.
- Spyropoulos-Antonakakis et al. (2015). Selective aggregation of PAMAM dendrimer nanocarriers and PAMAM/ZnPc nanodrugs on human atheromatous carotid tissues: a photodynamic therapy for atherosclerosis. *Nanoscale Research Letters 10,* 210, DOI 10.1186/s11671-015-0904-5.
- Sarantopoulou E., Gomoiu I., Kollia Z., Cefalas A.C. (2011). Interplanetary survival probability of Aspergillus terreus spores under simulated solar vacuum ultraviolet irradiation. *Planet Space Sci, 59,* 63–78.
- Kollia Z., Sarantopoulou E., Cefalas A.C., Kobe S., and Samardzija Z. (2004). Nanometric size control and treatment of historic paper manuscript and prints with laser light at 157 nm. *Appl. Phys., A, Mater. Sci. Process, 79,* 379– 382.

Switzerland

Breast cancer diagnostic with AFM

- Loparic, M., Plodinec, M., Lim, R. & Sum, R. (2013). Potentielle medizinische Anwendungen des Atomic Force Microscope. *Schweizerisches Medizin-Forum, 13*(41), 830-832.
- Plodinec M. et al. (2012). The nanomechanical signature of breast cancer. *Nature Nanotechnology, 7*, 757-765.

Magnetic racetrack memory

- Parkin S.S.P. (2012). Bits auf der Überholspur. *Spektrum Spezial Physik – Mathematik – Technik, 1,* 36-41.
- Parkin, S.S.P., Hayashi, M. & Thomas L. (2008). Magnetic Domain-Wall Racetrack Memory. *Science*, *320*, 190-194.

Carbon nanotube nets for electronics

- Gruner G. (2012). Kohlenstoffnanonetze für die Elektronik. *Spektrum Spezial Physik – Mathematik – Technik, 1,* 43-50.
- Baughman, R.H., Zakhidov, A.A. & de Heer, W.A. (2002). Carbon Nanotubes - the Route Toward Application*. Science, 297*, 787-792.

Converting sunlight to electric power

- Samulat G. (2012). Liegt die Zukunft unserer Energieversorgung in einer Verschmelzung von Photonik und Nanotechnologie? *Spektrum Spezial Physik – Mathematik – Technik, 1,* 30-32.
- Grätzel M. (2004). Conversion of sunligt to electric power by nanocrystalline dye-sensitized solar cells. *Journal of Photochemistry and Photobiology, 164,* 3-14.

C Contact Data Nano-Companies and Nano-Labs

Connect classes with the outside world of research in nanoscience and nanotechnology and high-tech companies

Switzerland

Below you will find the contact data of research laboratories in the field of nanoscience and as well the contact data of companies in the field of Nanotechnology. By the help of this list, teachers can bring school classes in direct contact with researchers and entrepreneurs. Based on the experience of the pilot, it is no problem to approach companies and researchers by phone or mail. In general, both entrepreneurs and researchers are willing to be involved with the students and to support the future generation of entrepreneurs and researchers.

Universities (Switzerland)

Institution	Contact	Area of Nanoscience
Universität Basel	+41 61 267 14 72 info(at)unibas.ch	Swiss Nanoscience Institute SNI
Universität Freiburg	+41 26 300 70 34 uni-info(at)unifr.ch	Adolph Merkle Institut (in Englisch)
Universität Bern	+41 31 631 31 75 info(at)unibe.ch	Institut für Anatomie
Universität Lausanne	+41 21 692 20 66 info(at)unil.ch	Nanopublic - Plateforme interdisciplinaire nanotechnologies et société (in Französisch)

Reference of the table : Swiss Nano-Cube Plattform:
http://www.swissnanocube.ch/en/science-research/forschungsinstitutionen-ch/universitaeten/

University of Basel: The *Swiss Nanoscience Institute (SNI)* provides a degree program in nanoscience. Schools are invited to visit the *SNI Visitor Center*, in addition talks and workshops at schools are organized.

SNI Communications & Events
Meret Hornstein MSc. nano
Klingelbergstrasse 82
CH-4056 Basel
+41 (0)61 267 15 21
Meret.Hornstein@unibas.ch

Swiss Universities for Technology

Institution	Contact	Area of Nanoscience
Eidgenössiche Technische Hochschule Zürich ETHZ	+41 44 632 40 39 info(at)ethz.ch	Micro and Nano Science Platform (in Englisch)
Eidgenössiche Materialprüfungs- und Forschungsanstalt EMPA	+41 44 823 45 92 info(at)empa.ch	Nanoscale Materials Science (in Englisch)
École Polytechnique Fédérale de Lausanne EPFL (in Französisch)	+41 21 693 21 78 info(at)epfl.ch	Center of MicroNanoTechnology CMI (in Englisch)
Paul Scherrer Institut PSI	+41 56 310 29 16 info(at)psi.ch	Laboratory for Micro- and Nanotechnology (in Englisch)

Reference of the table : Swiss Nano-Cube Plattform: http://www.swissnanocube.ch/en/science-research/forschungsinstitutionen-ch/eidg-hochschulen-und-institute/

Universities of Applied Sciences (Switzerland)

Institution	Contact	Area of Nanoscience
Nanoplatform - Swiss Universities of Applied Sciences	+41 32 321 63 81 peter.walther(at)bfh.ch	
Fachhochschule Ostschweiz	+41 81 755 33 62 info(at)fho.ch	NTB Buchs - Institut für Mikro- und Nanotechnologie MNT
HSR Hochschule für Technik Rapperswil	+41 55 222 44 02 forschung(at)hsr.ch	Institut für Umwelt- und Verfahrenstechnik UMTEC
Fachhochschule Nordwestschweiz	+41 56 432 43 80 info.technik(at)fhnw.ch	Hochschule für Technik - Institut für nanotechnische Kunststoff-Anwendungen INKA
Fachhochschule Nordwestschweiz	+41 61 467 42 42 info.lifesciences(at)fhnw.ch	Institut für Life Sciences
Fachhochschule Zentralschweiz	+41 41 288 40 34 info(at)hslu.ch	Kompetenzzentrum Fluidmechanik & Hydromaschinen
Fachhochschule Westschweiz	+41 24 557 28 00 info(at)hes-so.ch	Institut de Micro & Nano Techniques (in Französisch)
Berner Fachhochschule	+41 32 321 62 33 office(at)bfh.ch	Technik & Informatik - Angewandte Laser-, Photonik- und Oberflächentechnologien
Zürcher Hochschule für angewandte Wissenschaften	+41 58 934 75 26 info(at)zhaw.ch	Institut für Chemie und Biologische Chemie

Reference of the table : Swiss Nano-Cube Plattform:
http://www.swissnanocube.ch/en/science-research/forschungsinstitutionen-ch/universitaeten/

Companies (Switzerland)

Only a small selection of nanotechnology companies in Switzerland is listed below.

Company / Location	**Contact**	**Area of Nanotechnology**
BASF Basel	+41 61 636 48 88 berufsausbildung(at)basf.com	Nanobasierte funktionelle Farbstoffe, Elektronik und andere funktionale Anwendungen
CSEM Neuchâtel, Zürich, Muttenz, Alpnach, Landquart	+41 61 690 60 11 info(at)csem.ch	Muttenz: - Photovoltaik: thin-film Optik - Surface engineering: printable electronics
EMPA Dübendorf	+41 58 765 45 98 remigius.nideroest(at)empa.ch	- Nanomaterialien in Elektronik & Batterien - Forschungen zur Sicherheit von Nanotechnologie - Lithium-Ionen-Batterien etc. Laborrundgang/Führung kann an Fokus angepasst werden Die EMPA setzt zahlreiche Forschungs- und Entwicklungsvorhaben mit Partnern aus der Industrie um Technologietransfer-Infos für Industriepartner
EMPA St. Gallen	+41 58 765 74 74 info(at)empa.ch	- Plasmabeschichtungen für Textilien (H_2O-abweisend, schmutzresistent) - Silber- & Goldbeschichtungen von Textilfäden
IBM Research Rüschlikon	+41 44 724 81 11 info(at)zurich.ibm.com	Binnig and Rohrer Nanotechnology Center: - Cleanroom for micro/ nano-fabrication - “Noise-free” labs
Nanosurf AG Liestal, Baselland	+41 61 927 47 47 info(at)nanosurf.com	Entwicklung und Produktion von Mikroskopen (STM, AFM)
Roche Basel Roche Rotkreuz	Basel: +41 61 688 11 11 basel.visits(at)roche.com Rotkreuz: www.roche.ch – Rotkreuz - Kontaktformular	Basel: Nanotechnologie im Bereich Pharma Rotkreuz: Nanotechnologie im Bereich Diagnostics
Rolic Allschwil	+41 61 487 22 22 info(at)rolic.ch	Flüssigkristalle, LCD, Sicherheitselemente

Sensirion Stäfa ZH	+41 44 306 40 00 info(at)sensirion.com	Sensorik, Mikrotechnologie, Halbleitertechnologie
Straumann Entwicklung: Basel Produktion: Villeret (JU)	+ 41 61 965 11 11 info(at)straumann.com	Zahnimplantate

Further contacts you will find by the link below: There are listed around 50 nanotechnology companies. There is a brief description of every company and the link to the home page.

http://www.nanowerk.com/nanotechnology/Nanotechnology_Companies_Research_and_Degree_Programs_in_Switzerland.php

The i-net (innovation networks) provides contact to companies in the northwest of Switzerland: http://www.i-net.ch

The link below offers information about formation and professions in the nanofield: http://www.swissnanocube.ch/nanoteachbox/module/liste/#m30

Belgium

Below you will find the contact data of research laboratories in the field of nanoscience and as well the contact data of companies in the field of nanotechnology. By the help of this list, teachers can bring school classes in direct contact with researchers and entrepreneurs.

Universities (Belgium)

Institution	Contact	Area of Nanoscience
Universiteit Hasselt, IMO-IMOMEC	http://www.uhasselt.be/IMO	IMO (Instituut voor Materiaalonderzoek) focussed on the development of new materials with potential applications in the microelectronics, bioelectronics and nanotechnology.
The Nanoscience en Nanotechnology Centre of KU Leuven	https://fys.kuleuven.be/vsm/nano/aboutus.php	The Nanoscience and Nanotechnology Centre of the KU Leuven brings all research activities focussing in nanoscience and nanotechnology together.
Universiteit Antwerpen, Visielab	http://www.ua.ac.be/main.aspx?c=.BIMEF	Visielab research is focussed on the study of the biomechanics of the middle ear, where the cochlear implants have a central role.
KU Leuven, campus Diepenbeek, Embedded Systems & Security		The research is focussed on the development, evaluation and implementation of cryptographic algorithms and on the development of electronics systems for a safe sharing of information.

Companies (Belgium)

Company / Location	Contact	Area of Nanotechnology
Cochlear Benelux nv Mechelen, Belgium	+32 015 79 55 11 http://www.cochlear.com	Cochlear implants
Agfa Healthcare Mortsel, Belgium	+32 03/444 21 11 http://www.agfahealthcare.com/	Diagnostic Imaging
Imec Belgium Heverlee, Belgium	+32 016 28 12 11 info(at)imec.be	Image sensors and vision systems; thin-film electronic circuits for flexible RFIDs, flexible sensors, and flexible OLED displays; solar cells and batteries
Soltech nv Tienen, Belgium	+32 016 80 89 00 www.soltech.be	Design and development of Photovoltaic (PV) panels
NXP Semiconductors Belgium nv Leuven, Belgium	+32 016 39 06 20 http://www.nxp.com/	Small-signal, power and RF diodes; bipolar transistors; opto-electronics; LED Lighting; data

		converters; MOSFETs; media processors for automotive and consumer applications; microcontrollers
Phenom-World nv Eindhoven, Nederland	+31 40 259 7360 info(at)phenom-world.com	Desktop scanning electron microscopes and imaging solutions for submicron scale applications.
Xenics - infrared solutions nv Heverlee, Belgium	+32 016 38 99 00 http://www.xenics.com/en/contact	Designs and markets infrared imagers, cores and cameras of best-in-class image quality to support innovative R&D, industrial automation, machine vision, process control and high-end security applications
TP Vision Gent, Belgium	http://www.tpvision.com/	Smart TV and smart interaction features, new advancements in picture quality and Ambilight.
OMC Turnhout, Belgium	http://openmanufacturingcampus.com/	The **Open Manufacturing Campus** aims to be a physical place where innovative manufacturing companies can establish themselves. OMC is aimed at **production oriented companies** active in the **high tech, life sciences and medical technology sector**.
Triphase Heverlee, Belgium	www.triphase.be	Solutions for the fast realization of complex, high-performance, industrial power electronics applications including electric vehicles and power grid control.
DSP Valley	http://www.dspvalley.com/	DSP Valley is an umbrella organization mostly active in Belgium and The Netherlands. It unifies more than 80 high-technology enterprises and research groups, active in the micro- and nanoelectronics.

Estonia

Below you will find the contact data of research laboratories in the field of nanoscience and as well the contact data of companies in the field of nanotechnology. By the help of this list, teachers can bring school classes in direct contact with researchers and entrepreneurs.

Universities (Estonia)

Institution	Contact	Area of Nanoscience
University of Tartu	Maarika Lukk maarika.lukk(at)ut.ee phone: (+372) 50 39 780	Centre for Educational Technology, Institute of Education, Faculty of Social Sciences and Education
University of Tartu	Rünno Lõhmus runno.l6hmus(at)ut.ee phone: +372 737 4723	Laboratory of Low Temperatures, Department of Materials Science, Institute of Physics, Faculty of Science and Technology

Companies (Estonia)

Company / Location	Contact	Area of Nanotechnology
Estonian Nanotechnology Competence Centre	Rünno Lõhmus runno.l6hmus(at)ut.ee phone: +372 737 4723	Providing nanotechnological research and innovations particularly for the benefit of partnering manufacturing companies, or just put simply: to do research that has a direct output to industry. As an example of the past and still ongoing successful work – the smart glass project – is currently entering the industrialization phase.
Estiko Plastar LLT Tehase 16 Tartu, Estonia	Anne Ladva anne(at)estiko.ee phone: +372 7 308 376	Providing plastic packs for nutriments, peat, building materials and for other manufacturers, also providing various plastic products.
Andrese Klaasi LLT Betooni 9 Tallinn, Estonia	Gerd Veelma gerd.veelma(at)andres.ee phones: +372 50 99 680 and +372 60 61 320	Producing safety and security glass and offering cut-to-measure glass – matted, patterned and tinted – as well as mirrors.
Flydog Solutions LLC Energia 6a Tallinn, Estonia	Andri Laidre andri(at)flydogmarine.com phone: +372 565 5008	Developing own products concentrating mainly on innovative environment monitoring systems (hardware and software).
Saint-Gobain Ehitustooted LLT Peterburi tee 75 Tallinn, Estonia	Ain Inno ain.inno(at)e-weber.ee phones: +372 620 9529 and +372 50 333 04	Producing fine gravel and products of fine gravel, also selling these products and insulation materials and plaster products.
Tarmetec LLC Ringtee 6 Tartu, Estonia	Britta Peetso britta.peetso(at)metec.ee phone: +372 7385 071	Providing product development and manufacturing services for making parts of machines or machines (for medical, food, automotive and machine building industries). They have a wide variety of metal-working technologies available inside the company, which is an invaluable asset especially in

		manufacturing small- and medium-size batches. In addition, they are continuously finding smart technological solutions for manufacturing each part and perfecting each operation to its tiniest details.
Baltoil LLT Männi 1, Roiu, Haaslava vald Tartumaa, Estonia	Pekka Mononen pekka(at)baltoil.ee phone: +372 50 40 610	Blending and packaging of oils and chemicals, developing new products with leading European chemical and additive manufacturers and as well with Institute of Physics and Chemistry at University of Tartu. They are specialized in eco-packaging (for example: 3 litre bag package which is available in a self-service display pallet for stores).

Greece

Below you will find the contact data of research laboratories in the field of nanoscience and as well the contact data of companies in the field of nanotechnology. By the help of this list, teachers can bring school classes in direct contact with researchers and entrepreneurs.

Universities (Greece)

Institution	Contact	Area of Nanoscience
National Hellenic Research foundation	Tel. 2107273840 Email: ccefalas(at)eie.gr	Photonics for Nano-applications
Foundation for Research and Technology Institute of Electronic Structure and Laser	Τηλ. 2810391300 Email: liap(at)iesl.forth.gr	Laser Science, Micro/nano-electronics, Polymer Science, Materials Science and Astrophysics

Companies (Greece)

Company / Location	Contact	Area of Nanotechnology
NanoPhos SA	Tel: 22920 69312 Email: info(at)nanophos.com	Development, production and distribution of chemical products for cleaning and protection of surfaces and nanotechnology products.
Tropical-Nano	Tel: 210 5151099 info(at)tropical.gr	Development and manufacture of nanomaterials
Glonatech	Tel: 2106083465 Email: info(at)glonatech.com	Solutions, products and services for the construction of nanotech materials
Nanothinx	Tel: 2610-965208 Email: info(at)nanothinx.com	Carbon nanotubes (CNTs)
Nanotypos	Tel: 2310 365183 Email: info(at)nanotypos.com	optical devices, photonic applications, biotechnology, organic electronics applications energy harvesting

D List of criteria for the contest

This is the list of criteria used for the Quantum Spin-Off try-out contest: national and European. It may serve as an inspiration for teachers thinking of organizing a contest by themselves.

The aim of the presentation is for students to present their learning path throughout the contest to the jury as well as the people in attendance.

The list of criteria for the national juries is uniform in order to have comparable assessments between the 4 participating countries.

The points given to each participating team will not be made public to students, teachers or head of schools. Only the final ranking will be released to the public.

The duration of each presentation is 10 plus 5 minutes for questioning by the jury.

Ideally the jury is formed by at least 3 persons: researcher, business person, educational person. Every person fills out the list of criteria and at the end of all presentations the jury will combine their grades to produce the final score of each team. The final score is counted by adding the five scoring categories. The criteria are weighted equal.

The summary that each team is asked to produce is the basis for the presentation and is delivered to the educational member of the national jury.

The prizes will be awarded based on the marks given by the jury. For example, for the European contest four prizes were awarded to the participating schools following the classification based on the scores. For the national contest the procedure was the same, but the number of prizes in each country could be different. Every participating school receives a diploma, the winning classes receive a diploma in a frame and a prize. The head prize is a didactical equipment for the school. The other prizes are decided by the local organizers.

Criteria

The criteria for the jury of the contest are:

1 From modern science to technology
2 From technology to application
3 From application to business
4 Presentation
5 Creativity

During the spin-off day: The jury poses questions to allow students to display their level of understanding of the underlying modern science/quantum physics concepts, of the scientific literature, technology and business idea. Questions can also be posed by the audience.

A form of the list of criteria to print is added at the bottom of the document. The five criteria are explained below:

From modern science to technology

The students should display sufficient understanding of modern science/quantum physics concepts. Based on their experiences from the learning stations and their work in their classroom students present the scientific concepts which served as the starting point for their virtual product and spin-off company. A specific part of the booklet will be dedicated to this.

Furthermore the students present their interactions with researchers and relevant literature. A scientific article that influenced the creation of the spin-off company should be briefly presented and students explain its influence on the virtual product and spin-off company.

From technology to application

The students describe their interaction with the NanoLab and researchers, what they learned from the dialogs/questions with the researcher and how these interactions inspired their creative process.

Then students present the virtual product and explain the creative process. The product should be:

- socially relevant and is making life better in meaningful way
- realistic, can be virtual but there must be shown some potential to make it
- consideration about responsible research and innovation (RRI) (for a definition of RRI see http://www.rri-tools.eu/about-rri)

From application to business

The students have well thought about the 9 elements of The Business Model Canvas (BMC) making a valorization of the paper by founding a virtual company. The 9 elements of BMC are:

1. Key Partners
2. Key Activities
3. Key Resources
4. Value Propositions
5. Customer Relationships
6. Channels
7. Customer Segments
8. Cost Structure
9. Revenue Streams

Presentation

The criteria for the presentation are:

- Presentation technique
    - enthusiasm and energy (depending on: pronunciation, loudness, speaking by heart or with only one small card, self-confidence, looking at the public, stimulating elements, suitable dressed for the event)
    - team contribution by all team members
    - use of visual aids – effective use of multimedia and / or other
- Presentation composition
    - clear and concise explanations provided
    - effective use of time (presentation structure, in time)

Creativity

An important part of the contest is dedicated to fostering students' creative potential and providing them with an opportunity to problem-find and problem-solve, making connections, explore their ideas, ask questions of themselves and others and experience or simulate the creative process of an entrepreneur. The degree of novelty in the students' work is taken into account.

Questions for students to take into account:

- Have you considered whether a similar idea already exists in the market? If that's the case, what is the added value of the group's proposal?
- Does the product offer creative solutions to solve existing problems in the field?
- To what degree does the business idea change the industry/customer behaviour?

Team Assessment Form

ASSESSMENT CRITERIA		Insufficient	Sufficient	Good	Very Good
1	From modern science to technology	1	2	3	4
2	From technology to application	1	2	3	4
3	From application to business	1	2	3	4
4	Presentation	1	2	3	4
5	Creativity	1	2	3	4
TOTAL					

E Country-specific information

Belgium

Ambassadors in the class

In Belgium the activity “Ambassadors in the class” was organized in the frame of the Quantum Spin-Off contest. The classes participating presented their work, pathway, product and related spin-off company, to at least one other class of their school. This served multiple purposes: reach other students and teachers which could be at their turn inspired by the Quantum Spin-Off pedagogy, and on the other hand give to the participating students an opportunity to practice their presentation before in view of the spin-off day. Such an activity can also be foreseen by the teachers willing to organize a try-out. Of particular interest could be present the work done by the students of a sixth year “Secundaire Onderwijs” to students of a fifth year (that could be inspired to undertake the same pathway the following school year.

Role of DSP Valley

In Belgium, most of the company visits were organized thanks to the support of the umbrella organization DSP Valley, mostly active in Belgium and The Netherlands. It unifies more than 80 high-technology enterprises and research groups, active in the micro- and nanoelectronics. Useful information about the world of nanotechnology enterprises in Belgium can be found on DSP Valley website. The contact details are reported in the table above (see part C: Contact Data Nano-Companies and Nano-Labs).

Belgian website

Useful information and support, in particular for Belgian teachers, can also be found on the Belgian website of the project: http://spinoff.vakdidactiek.be/.

Estonia.

How did students prepare for the contest?

The students studied different topics related to the project by reading articles and participating in a class at their own school where the teacher introduced the topic theoretically and carried out practical experiments. They also took a course titled “Materials used in regenerative medicine”. Educational technologist Ly Sõõrd told the students which methods should be used to process scientific articles in order to find desired information faster and more efficiently when thinking about the products made by the student group. She introduced the search methods and environments. Sociologist Jüri Ginter explained how to participate in teamwork. He gave an overview of the principles of teamwork, and the students practised teamwork themselves. For instance, students in small groups had to solve a specified problem or task and present the solution to the other groups. Expert in materials science Martin Järvekülg introduced the theory and applications of regenerative medicine. The topics included lab-grown tissues and organs and using the electrical properties of nanomaterials. One of the nanotechnological applications mentioned was nanoskin, a web of nanofibers that has many qualities similar to those of the human skin. Research assistant in the

Gifted and Talented Development Centre of the University of Tartu Viktoria Neborjakina told how to be creative and think more out of the box. During the project, the students did a lot of independent work. The results were shared through Google Drive. The students also visited different science centres and at least one company or establishment.

Student projects in Estonia

In Estonia, seven projects by students were prepared. In every project, the students had two tasks:

- develop a product which is related to nanotechnology; and
- propose a business model for the distribution of the product.

The business model was to include the key partners, key activities, key resources and a value proposition. The students were also asked to consider how to build customer relationships, market their product and which channels to use.

Topics of the projects:

- Materials in regenerative medicine (material that would cover wounds and support the healing process)
- Artificial muscle wristwatch
- Nanoparticles and ionic liquids as oil additives (ionic liquids enriched bike lubricant)
- Wastewater fuel cell (to get electrical energy from wastewater produced daily)
- Materials in regenerative medicine such as collagen-coated implants
- Thorium as a source of nuclear energy
- Nanoscale electric generator (nanosprings that produce electricity)

Greece

Nanotechnology as a socioscientific issue

Students and teachers participating in the Quatnum Spinoff contest spent a significant part of their interactions with researchers of the NHRF (Dr. Cefalas, Dr. Sarantopoulou) learning about the societal effects of nanotechnology and the immediate effects that this strand of science has on their everyday life. The researchers devoted a large part of their presentations and discussions on the potential that research in nanotechnology has to produce high-tech materials that could tremendously improve living standards through various sectors of industry (e.g. medical applications, energy conservation). A variety of examples of everyday products developed through research were highlighted along with details on the actual process of transferring scientific research to industry.

A large part was also devoted on the issue of regulation of the high tech products in terms of health concerns and mainly the toxicity levels of certain nanotechnology applications. This topic highlighted various issues on how society views and uses scientific research applications as consumer products, with the issue of public safety and the need for longitudinal studies on the effects of said products on public health. The issues mentioned above opened a discussion on the value of school science education and the need for including current topics, such as nanotechnology, in the curriculum to inform students on both the relevance and the effects of science in everyday life.

A final topic that is relevant to the situation in Greece at the moment, is the potential benefits for the economy that focusing on high tech scientific research might have. The NHRF researchers brought up the issue that nanotechnology (both research and applications) provides a field that, if targeted by the state as a priority, could offer economic growth and open up employment positions for a large number of people, not only scientists. This can be seen as an important part of the researcher-student interaction as it provided information and initiated discussions closely connected to the financial situation in the country, but with the focus on how to find ways to overcome the current difficulties on both personal and country levels.

Switzerland

Proposals for classroom activities to understand nano risks

Students participating in the *Quantum Spin-Off* project observe the interrelationship between nano research and nanotechnology. As a further step, the risks of nanotechnology can be examined.

Learning objective: … develop a personal perception of the risks of nanomaterials on the basis of research findings.

For the booklet that the students prepare as part of the *Quantum Spin-Off* project, an additional learning objective can be added: drafting a statement regarding the transfer of research findings to a spin-off company (e.g. weighing up benefits and risks, estimating social consequences, "anticipating the future")

To download the additional learning station in German with the title “Proposals for classroom activities to understand nano risks” see the project website:

http://ch.qs-project.ea.gr/en/content/lernstationen

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)