International Conference NEW PERSPECTIVES in SCIENCE EDUCATION
2nd Edition

International Activities in Nanoscale Science and Engineering Education

Anna-Maria Bach, Thomas Waitz*
Department of Chemistry Didactics, Georg-August-University Göttingen (Germany)
anna-maria.bach@stud.uni-goettingen.de, twaitz@gwdg.de

Abstract

Scientists in Europe and the USA have already recognized the potential of nanoscale science and engineering as an emerging field of technology [1,2]. Roco stresses the fact that 2 million nano-trained workers will be needed worldwide until 2015, hence, there are several initiatives all over the world trying to satisfy the growing demand for a highly qualified workforce [1,2]. This requires the development of methods and programmes for "Nano Education" at K-12 and university level so that students become aware of nano-careers they could pursue. In addition, professional teacher training courses and in-service training need to be implemented in order to help teachers become nano-literate [3]. Due to this, the article aims on showing that nanoscale science and engineering can serve as catalyst for educational reforms [4]. It will be argued that nanoscience is not a single discipline but rather an interdisciplinary one highlighting the connections between sciences [3]. Therefore, "Nano Education" challenges the traditional science curricula and the way sciences have been taught so far. Through literature study different international approaches to nanoscale science and engineering education at K-12 and university level will be analysed and restructured. National initiatives and trans-national approaches will be compared in order to provide an overview of the variety of options that can be chosen to incorporate nano-contents into the science classroom. Furthermore, it will be discussed how nano-concepts can be included into the existing science curriculum since research findings suggest that the already overcrowded curriculum is one of the main barriers to teaching "Nano" [3].

1. Introduction

Feynman (1960) once raised the question: "What would happen if we could arrange the atoms one by one the way we want them" [5]. Up to the present this idea of re-arranging single atoms and molecules has produced a completely new and steadily growing field of technology. According to several scientists, researchers and economists nanotechnology (*below synonymously referred to as nanoscale science and engineering*) has become the key technology of the 21st century (*e.g.* [6], [7]). Although the industry recognized the potential of nanoscale science and engineering (NSE) different American and European surveys illustrate that the public has little awareness about it (*e.g.* [8], [9], [10]). While the nano-sector is rapidly growing researchers address the need for a "Nano Education" since sooner or later every person is going to be confronted with making decisions about nano-related issues concerning his or her everyday life [11].
Furthermore, a survey carried out by the American scientists Roco, Mirkin and Hersam suggests that there will be a shortage of nano-workers in future [12]. The authors argue that 6 million qualified workers will be needed worldwide until 2020 – compared to Roco's prognosis for 2015 the estimated amount of nano-workers is going to triple until 2020 [2,12]. There are other scientists questioning the validity of these estimations (*e.g.* [13], [14]), however, due to the predicted shortage, a strategic plan was implemented in 2004 by the U.S. government in which the development of educational resources and of skilled workers is defined as one out of four major goals [15]. One year later this attempt was followed by the "Action Plan for Europe 2005-2009" introduced by the European Commission that highlights the need for an interdisciplinary education and training in nano-related fields [16]. In the following an overview will be given of the current discussion of incorporating nano-contents into the science classroom.

2. The Interdisciplinarity of Nano

Nano is first and foremost a prefix referring to the size and scale of particles and structures in the range of 0.1 to 100 nanometres. This prefix can be linked to everything from medicine to engineering, from chemistry to biotechnology and so on. Hence, nano-workers should possess a comprehensive knowledge of different disciplines. The multi- and interdisciplinary nature of NSE comes into conflict with the American and European education system that is based on specialising in single disciplines the further one proceeds one's educational career [7]. Consequently, future scientists and technicians that are working in the field of nanotechnology will discover skill gaps if the education system is not able to react to the needs NSE is requesting. Roco argues that *Nano* should "penetrate the education system" by introducing nano-contents at all levels from preschool to university [2]. He suggests reversing the so called *pyramid of learning* to promote unity in nature while introducing students to the methods and themes that are common across disciplines first. Turning the curricular science education upside-down should enable students to see the interdisciplinary connections between sciences from the very beginning of their educational career (see fig.1) [2].

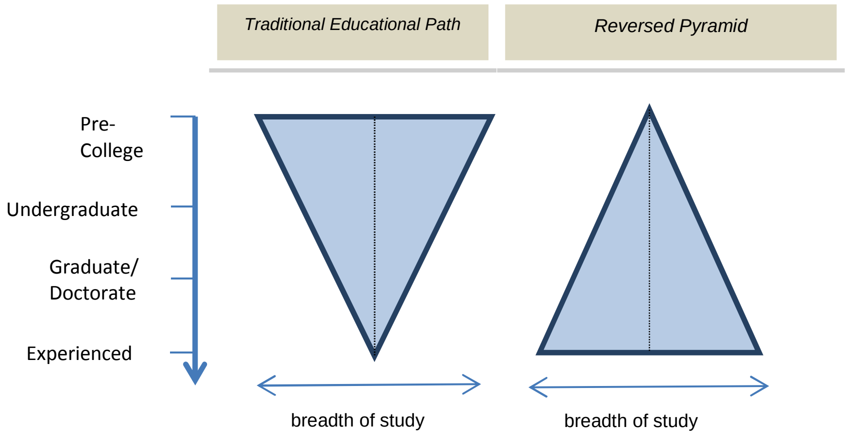

Figure 1: Reversing the „Pyramid of Learning" [2].

Roco's approach has been refined by the European researchers Baraton, Monk and Tomellini (2008). They suggest that students should gain an in depth education in single disciplines while maintaining a coherent understanding of features across sciences what they call "common knowledge" [1]. Instead of a curriculum that is based on specialisation, they are opting for a curricular design based on their so called "Hourglass Approach" (see fig.2).

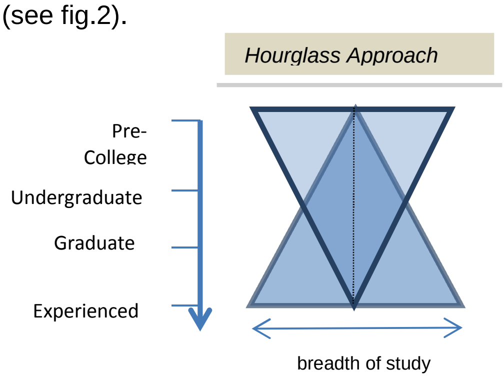

Figure 2: Hourglass Approach [1].

Although both approaches highlight the interdisciplinary character of NSE they do not specify how the implementation of nano-contents in secondary and tertiary education should look like.

3. Where Does Nano Fit in the Curriculum?

3.1. Nano Education at K-12 level

For secondary education American scientists and educators agreed on the so called "Big Ideas" – *i.e.* central concepts that should be taught in school (*e.g.* [17], [18], [19]). In different workshops nine concepts have been identified all of which are belonging to the four essential areas of NSE: Processing, Nanostructures, Properties and Application [19].

Instead of incorporating new modules and contents into the existing K-12 curriculum teachers should rather focus on the "Big Ideas" since they can serve as tools for unifying the traditional school disciplines [20], thus, they can foster interdisciplinary learning. The list given below follows the suggested concepts by Wansom et al. [19]:

1. ***Size and scale***: students should be able to analyse factors relating to size and scale in order to describe matter and predict its behaviour.
2. ***Surface-to-Volume-Ratio***: students should describe the surface-behaviour of nano particles that is due to the fraction of atoms.
3. ***Surface-Dominated-Behaviour***: students should investigate the impact of forces and interactions relevant at the nanoscale since these changes with scale.
4. ***Self-assembly***: students have to gain knowledge about this process in which materials can spontaneously assemble into organized structures.
5. ***Quantum mechanics***: in order to understand the size-dependent properties at the nanoscale, students need to acquire knowledge about quantum mechanics especially about the dual particle-wave nature of matter.
6. ***Size-Dependent Properties***: students should be able to distinguish between surface- or bulk-dominated properties of matter.

Apart from these concepts further ones have been mentioned: *tools and instruments, models and simulations* and *societal impacts* [19].

The most considerable approaches of including the “Big Ideas” into the existing curriculum have been carried out in the U.S. (*e.g.* [17], [18]). One example provides the NanoSense project (http://nanosense.org/) that has been funded by the U.S. National Science Foundation [17]. NanoSense offers four curriculum units including teaching materials, power point slides, worksheets and hands-on activities; the first unit “Size Matters” is structured like an introductory guide to NSE whereas the other three – “Clear Sunscreen”, “Clean Energy” and “Fine Filtration” – give examples of applications. The NanoSense curriculum is directed towards high school chemistry teachers; nevertheless, in the implementation phase the introduction of the contents has also been tested in biotechnology, biology and environmental classes. The main outcome of the evaluation is alarming since the biggest barrier for implementing “Nano” in class has been the teacher’s own knowledge and his or her comfort level with the materials [17]. Hence, no matter what kind of programme or workshop is offered to high school students, it is highly important to promote teacher learning, too.

3.2. Nano Education at university level

There are researchers arguing that the most appropriate level for teaching nano-contents is the university level and above (PhD) since studying nano-related issues requires an in depth knowledge in sciences (*e.g.* [21]). Up to the present universities worldwide implemented NSE courses in undergraduate, graduate and doctoral studies (see fig.3).

It should be noted that individual countries invest in different paths of NSE Education. Europe focuses on graduate programmes (78), whereas the U.S. supports PhD programmes (47) (fig. 3). Also single European countries prefer different educational programmes: Norway for instance only offers PhD courses (5) while France has none, instead students can choose among a variety of graduate courses (18) (fig. 3). Germany and the UK offer a comparable amount of nano-programmes in total (Germany 27; UK 31) but the proportional distribution differs for the single courses of education offered (fig. 3).

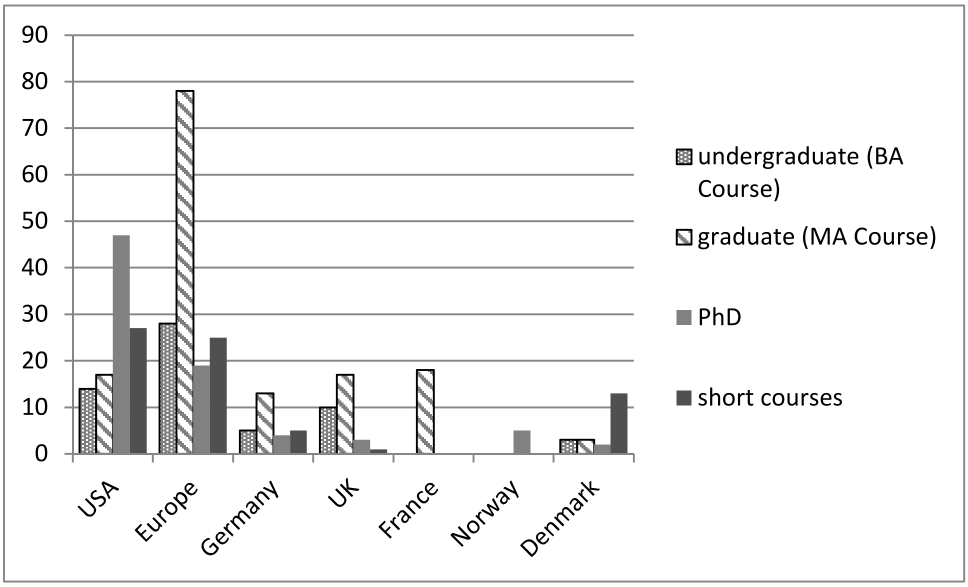

Figure 3: Number of undergraduate, graduate, PhD and short courses (like summer schools) offered per country. Data for Europe: based on the Nanoforum Education Catalogue 2005 [22]; data for the USA: based on NNI homepage www.nano.gov/education-training [23].

All of these courses and programmes are contentwise quite different; there are programmes focusing on biology and chemistry and others on engineering and physics [22]. There is little transparency about the quality of these programmes, their content-related orientation and the degree of interdisciplinarity offered. Due to this, the Nanoforum initiative originally funded by the European Commission published an Education Catalogue to allow students and industry to compare European NSE programmes [22].

4. Discussion

In can be concluded that NSE education at university level seems to be more popular than at school level as measured by the number of publications as well as programmes and teaching materials offered. Besides, there remain a number of future challenges. For tertiary education standards should be developed to guarantee high quality and transparency of Bachelor-, Master and doctoral programmes. Additionally, a strong collaboration between industry and academia should be aspired to make sure that students gain all skills relevant for their future jobs by studying Nanotechnology [13]. For secondary education teacher training courses in NSE are most vital since student's achievements depend on teacher quality which becomes obvious in the NanoSense study [17].

References

[1] I. Baraton, R. Monk, R. Tomellini (**2008**): "European Activities in Nanoscience Education and Training." In: Sweeney & Seal: *Nanoscale Science and Engineering Education*. CA: American Scientific Publ., 459-471.

[2] M. Roco (**2003**):"Converging science and technology at the nanoscale: opportunities for education and training." In: *Nature Biotechnology* 21 (10), 1247-1249.

[3] N. Healy (**2009**):"Why Nano Education?" In: *Journal of Nano Education* 1, 1-6.

[4] P. Schank, J. Krajcik, M. Yunker (**2007**): "Can Nanoscience Be a Catalyst for Educational Reform?" In: Allhoff et al. (eds.): *Nanoethics: The ethical and social implications of nanotechnology.* Hoboken, NJ: Wiley- Interscience, 277-290.

[5] R. Feynman (1960): "There is plenty of room at the bottom. An Invitation to Enter a New Field of Physics." In: *Caltech Engineering and Science* 23 (5), 22-36.

[6] L. Albicht et al. (**2006**): "Identification of Skill Needs in Nanotechnology." In: *CEDEFOP Panorama Series* 120. Luxembourg: Office for Official Publications of the European Communities.

[7] K. Deppert et al. (**2008**): "Engineering Nanoscience: A Curriculum to Satisfy the Future Needs of Industry." In: A. E. Sweeney & S. Seal (ed.): *Nanoscale Science and Engineering Education*. CA: American Scientific Publ., 481-505.
[8] O. Castellini et al. (**2007**): "Nanotechnology and the public: Effectively communicating nanoscale science and engineering concepts." In: *Journal of Nanoparticle Research* 9, 183-189.
[9] M. Cobb & J. Macoubrie (**2004**): "Public perceptions about nanotechnology: Risks, benefits and trust." In: *Journal of Nanoparticle Research* 6, 359-405.
[10] Royal Society and Royal Academy of Engineering (ed.) (**2004**): "Nanotechnology: views of the general public." Online: http://www.nanotec.org.uk/Market%20Research.pdf, accessed: 02.12.2012.
[11] A. Laherto (**2010**): "An analysis of the educational significance of nanoscience and nanotechnology in scientific and technological literacy." In: *Science Education International* 21 (3), 160–175.
[12] M. Roco, C. Mirkin, M. Hersam (**2010**): "Nanotechnology Research Directions for Societal Needs in 2020 - Retrospective and Outlook." *WTEC Study Report,* Online: http://www.wtec.org/nano2/Nanotechnology_Research_Directions_to_2020/, accessed: 19.12.2012.
[13] I. Malsch (**2008**): "Nano-education from a European perspective." In: *Journal of Physics* Conf. Ser. 100, IOP Publ.
[14] R. Monk & A. Rachamim (ed.) (**2005**): *Research Training in Nanosciences and Nanotechnologies. Proceedings of the Workshop Held in Brussels, 14-15 April 2005.* Online: ftp://ftp.cordis.europa.eu/pub/nanotechnology/docs/educationworkshop_proceedings.pdf, accessed: 11.12.2012.
[15] National Science and Technology Council; Committee on Technology; Subcommittee on Nanoscale Science (ed.) (**2004**): *National Nanotechnology Initiative. Strategic Plan.* Online: http://nano.gov/sites/default/files/pub_resource/2011_strategic_plan.pdf, accessed: 09.12.2012.
[16] European Commission (ed.) (**2005**): *Nanosciences and nanotechnologies: An action plan for Europe 2005-2009*. Brussels, Online: http://ec.europa.eu/research/industrial_technologies/pdf/nano_action_plan_en.pdf, accessed 09.12.2012.
[17] P. Schank et al. (**2009**): "Can High school Students Learn Nanoscience? An Evaluation of the Viability and Impact of the NanoSense Curriculum." In: *SRI International,* Online: http://nanosense.org/documents/reports/FinalEvaluationReport.pdf, accessed: 02.10.2012.
[18] S. Y. Stevens et al. (**2009**): *The Big Ideas of Nanoscale Science and Engineering. A Guidebook for Secondary Teachers.* Arlington: NSTA Press.
[19] S. Wansom et al. (**2009**): "A Rubric for Post-Secondary Degree Programs in Nanoscience and Nanotechnology." In: *International Journal of Engineering Education* 25 (3), 615-627.
[20] A.-L. Kähkönen et al. (**2011**): "Intrinsic and Extrinisic Barriers to Teaching Nanoscale Science." In: *Journal of Nano Education* 3 (1), 1–12.
[21] T. Kulik & J. Fidelus (**2007**): "Education in the Field of Nanoscience." Nanoforum Publ., Online: http://www.nanoforum.org/, accessed: 09.12.2012.
[22] Nanoforum (ed.) (**2005**): *European Nanotechnology. Education Catalogue.* Online: http://www.nanoforum.org/, accessed: 09.12.2012.
[23] NNI (ed.): "College and Graduate Programmes", online available: *http://www.nano.gov/education-training/university-college*, accessed: 04.01.2013.

NSF's NanoJapan International Research Experience for Undergraduatesâ€” Recognized as a model for international education programs for science and engineering students, NanoJapan provides U.S. undergraduates with structured research opportunities in Japanese university laboratories with Japanese mentors.Â SUNY Polytechnic Institute Colleges of Nanoscale Science and Engineering â€“ M.S. in Nanoscale Science; M.S. Nanoscale Engineering. University of California, Riverside â€“ Online M.S. Nanotechnology Engineering. University of California, San Diego â€“ M.S. Nanoengineering. Nanotechnology education involves a multidisciplinary natural science education with courses such as physics, chemistry, mathematics and molecular biology. It is being offered by many universities around the world. The first program involving nanotechnology was offered by the University of Toronto's Engineering Science program, where nanotechnology could be taken as an option. Nanoscale science and engineering education activities in the United States. Journal of Nanoparticle Research, 4, 271-274. Schank, P., Krajcik, J., & Yunker, M. (2007).Â Teaching and learning in nanoscale science and engineering: A focus on social and ethical issues and k-16 science education. Material Research Society (0931-KK03-05). Boston, MA. â€œInternational Concept on Nano-science and Nano-engineering Education and Research. Trainingâ€ Tadashi Itoh, Professor, Division of Frontier Material Science, the Graduate School of Engineering Science, Osaka University, Japan. Itoh specializes in experimental research works on laser spectroscopy of nano-structured materials.Â â€œBest Practices for the Professional Development of Teachers in Nanoscale Science and Engineeringâ€ Lynn Bryan, Professor, Science Education, Purdue University. Bryan is a science educator who has conducted research, teaching, and engagement activities in numerous countries including China, Mexico, Honduras, Japan, and the Philippines.