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The world of the smallest parts[1]

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Nanotechnological coatings use the same physicochemical principles as the Lotus flower and thereby remain permanently clean. This is only one example of numerous applications of nanotechnology that are also now starting to be usable in the professional world (such as architecture and building). In order for such examples to actually be used, however, it is necessary to create awareness of nanotechnology at the levels of vocational and professional education.

Nanotechnology deals with unimaginably small objects. A thought experiment should make this clear: attempt to split a single human hair into two parts. This seems to be an achievable, albeit difficult, task. Now attempt to split the same hair into 500 equally sized parts. This seems to be impossible, both from mechanical and optical considerations. A human hair has a diameter of approximately 50,000 nanometres (nm). Our imaginary splitting of hair would, therefore, create hair fragments with diameters of 100 nm. This is the upper boundary of the nanoscale, below which the business of nanotechnology takes place. In this realm new properties of materials are exploited, which only emerge when materials are structured in the nanoscale. Compared with the same materials in macroscopic form, the nanomaterials may have superior chemical reactivity, qualitatively different optical properties and better mechanical stability.

Applications of nanotechnology are already widely available in everyday life. A glimpse into the "Nanorama-Loft",[3] which is meant to represent a typical studio flat inhabited by a student or young professional, reveals ten consumer products that either contain nanomaterials or are prepared with the help of nanotechnological processes (nanomanufacture): a snow shovel (made from ultralight, ultrastrong nanocomposites in turn made by incorporating nanofibres into a polymer matrix); impregnating spray for waterproofing leather and other materials (containing nanosized macromolecular droplets); a pair of skis (nanocomposites); ski goggles (nanocomposite frame and eye shields incorporating nanosized, hence perfectly optically clear, ultraviolet-absorbing particles); a bicycle whose frame is made from a nanocomposite material;

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[1] The text has been adapted and translated from *Die Welt der kleinsten Teile*, published in *Folio*, No 1 (2011), pp. 48–51.

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[3] www.swissnanocube.ch/nanorama

Nanotechnology Perceptions **8** (2012) 149–153
Received 1 May 2012

bicycle tyres, similarly made from nanocomposites; a badminton racket (nanocomposite); and overtrousers, overcoat and overshoes with superlative thermal barrier and water-resistant properties. The most impressive contemporary manifestation of nanotechnology is in electronics: apart from the impressively small and lightweight “notebook” computers and “smartphones”, most other electronic devices such as cameras and satellite navigation instruments rely on nanoscale components to achieve their essential portability. The results of this miniaturization, in turn dependent upon component nanification, influence daily work and private activities in essentially equal measure.

On a very different scale is the nanotechnological treatment of surfaces. By nanostructuring a surface in a specific fashion in multiple length scales, mimicking the naturally grown structure of the lotus, surfaces can be made ultrahydrophobic. As a result, water drops falling on such modified surfaces assume a spherical form and readily roll off, carrying dirt particles with them. The surfaces of the lotus plant are thereby maintained permanently clean, and the phenomenon is called the “lotus effect”. Textiles, facades, glass windows and car bodies can be ultrastructured in this way (sometimes by simply spraying an appropriate coating onto them), and thereby become self-cleaning. The benefits for architecture and automobilists are obvious.

The Swiss “Nano-Cube” project

Nowadays nanotechnology is the foundation for the development of new and innovative products and processes in many industrial branches, not only in electronics. Numerous nanotechnological products and methodologies are currently available for use in the construction industry, as detailed in Table 1. In order to exploit these inventions, institutions of basic, further and continuing education must necessarily be or become aware of them and ensure that comprehensive knowledge about them is transmitted to their students. Nevertheless, the pace of invention and the introduction of innovative products onto the market place presently far exceeds what should be the parallel introduction of corresponding teaching in educational establishments about the materials from which the products are made, how they are fabricated, what are their properties and how they can be used, and similarly for processes reliant on nanotechnology. Nanotechnology is still today essentially an area of research that is only seriously encountered at the highest level of education, that of the doctorate (PhD). The absence of nanotechnology as a subject at the preceding, and economically far more important, levels of education concerned with forming technicians, engineers and other technical experts, is now hampering the introduction of advanced technologies into the economy.

In order to fill this evident gap, the “Innovationsgesellschaft” together with the Swiss Federal Institute for Vocational Education and Training (Eidgenössisches Hochschulinstitut für Berufsbildung, EHB) have launched the “Nano-Cube” platform[4] with the support of the Swiss Federal Office for Professional Education and Technology (BBT). The platform offers extensive didactic materials for teaching and professional education as well as diverse background information about nanotechnology useful for any member of the public interested in this new technology.

For example, the “Nanorama game” offers a virtual glimpse into an ordinary domestic apartment filled with everyday, household objects, many of which contain nanoproducts.

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[4] www.swissnanocube.ch

Table 1. Applications of nanotechnology in the construction industry.

Domain	Application
Cement-based construction materials	Nanomaterials as additives improve the rigidity, durability and workability of concrete and mortar.
Paint and varnish	Nanoscale ingredients can function as (for example) photocatalysts capable of destroying dirt and malodorous or harmful substances; they can protect wood and other services from ultraviolet irradiation; and they can function as fungicides or bacteriocides. Nanoscale pigments can introduce completely novel colour and reflexion effects (for example, "flip-flop" effects). The quality of surfaces can be significantly enhanced using coatings containing nanoscale components, which can, for example, confer anti-graffiti properties.
Glass	Numerous applications; for example, improved thermal barrier properties, protection from sunlight (electrochromic materials), self-cleaning (incorporating photocatalysts on the surface), and anti-reflexion coatings.
Thermal barriers, sound insulation and fire protection	Nanogel foams (aerogels) function as highly efficient, very thin and transparent heat and sound barriers. The fire-resistant properties of (for example) electric cable jacketing can be significantly enhanced by using nanostructured silicate particles as a filler for the jacketing material matrix.
Energy sources and renewable energy storage	Light-emitting diodes (LEDs), including organic light-emitting diodes (OLEDs), convert electricity into light with high efficiency (i.e., with very little heat production). Nanotechnology can be used to create low-cost thin film and dye-based photovoltaic solar cells. Nanostructured membranes and catalysts lower the cost and enhance the performance of fuel cells used for the production of electricity and heat.
Interior decoration	The incorporation of modified nanoparticles into coatings confers onto them anti-dirt properties and resistance to the adhesion of biological objects (including microbes). Such nanoparticles can also greatly enhance the possibilities for joining and sealing materials such as ceramics, stainless steel, glass and wood.

Internet browsers navigating to the site[3] can move their mouse-driven cursor around the apartment and when they find a "nanoproduct" (i.e., one containing nanomaterials or fabricated with the assistance of nanotechnology) a technology-related question (with multiple-choice answers) pops up upon clicking on the product's image designed to test the user's knowledge. This is about nanotechnology. For example, "due to the incorporation of carbon nanotubes in the frame, (a) a badminton racket can be used indifferently by right-handed and left-handed players; (b) a badminton racket can also be used as a tennis racket; (c) the racket has a high stability and low weight." Uncontroversially, in this case (c) is considered to be the correct answer.[5] The game is constantly updated, by adding new objects and changing the questions asked about the old ones. A further click brings up additional product information in the form of a brief description. In the case of the racket, this information is "like with tennis rackets, carbon

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[5] The answer provided might not always meet with universal approval. For example, by clicking on the bathtub the question posed is "bathtubs, washbasins and shower cabinets (a) can be cleaned much more easily thanks to nanotechnology; (b) thanks to nanotechnology they will in future be foldable, enabling them to be stored away after use, saving space; (c) thanks to nanotechnology they release

nanotubes (CNTs) can be incorporated into the frames of badminton rackets. CNTs are stronger than steel and have a lower density than aluminium. While keeping the same stiffness, the racket can be made lighter. The nanoscale carbon nanotubes are able to fill the spaces between the microscopic (i.e., not in the nanoscale) carbon fibres already incorporated into racket frames and together with the latter form a supercomposite material. Deeper mechanistic explanations, delving into the chemistry and physics underlying the technology, are typically not given—the intention of the game is to provide an initial introduction to someone without a university education in the physical sciences encountering nanotechnology essentially for the first time.

The NanoTeachBox

The NanoTeachBox contains didactic material for teaching and learning, such as videos, presentations and much additional information useful for teaching. In deference to the Year of Chemistry (2011), a nanochemistry module was developed, with the support of the Metrohm Foundation in Herisau. This module contains extensive introductions for experimentation and is conceived for use in the vocational training of laboratory staff and for chemistry teaching in secondary schools. The featured experiments include nanoparticulate gold, nanoparticulate iron, magnetic liquids (ferrofluids; that is, suspensions of nanoparticulate ferromagnetic materials), and liquid crystals. A foundation module providing a first entry into the nanoworld has also been created, along with several others, and new ones are constantly being added. A module specially conceived for general education (Allgemeinbildender Unterricht, ABU) focuses on the opportunities and risks of nanotechnology. For the vocational clusters chemistry/physics, retail trade/sales, construction, metal/machines and medicine/cosmetics, short modules (called "Nano-Flash") have been constructed, based on (typically three) short (20 minute) sequences intended to be incorporated into existing curricula (for example, in materials science and technology). The material in the NanoTeachBox is prepared with the assistance of experienced teachers interested in microtechnology and nanotechnology, who are offered the possibility of working with the Nano-Cube team during one of their regular sabbaticals.

A repeatedly encountered question is whether the nanomaterials that are now found in a great variety of consumer products, including cosmetics, packing materials, colouring materials, cleaning materials, textiles, automobile accessories, electronic devices and sports articles, are dangerous. It is not possible to give a generally valid answer to this question because the "nano" epithet applies to a great diversity of materials. The principal discussions about risk concern above all the hazards presented by free nano-objects; for example, nanoparticles that are not embedded in a paint or polymer matrix. In Switzerland, various

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one's favourite perfume for months." (a) is given as the sole correct answer, but an expert in the field will point out that this is only correct in the rather limited context of currently available commercial products (and anyway answer (b) explicitly refers to the future). Answer (c) is certainly achievable using perfume-containing nanocapsules embedded in the basin material and (b) likewise looks realizable, although of dubious practical benefit. Nevertheless, to go into such depth would defeat the object of the game, which is to provide a readily accessible entry into the world of nanotechnology for the typical citizen; it should be borne in mind that even in Switzerland, a country with an economy based on high technology, a highly developed educational system and a serious and informative press, a majority of citizens seem not yet to be aware of what nanotechnology is. In other European countries and in the USA awareness is typically even lower, in many cases significantly so.

federal government offices have already addressed this concern. Already in 2008 the Federal Government promulgated an action plan for introducing measures essential to ensure the safe handling and processing of nanoparticles. The action plan also envisaged that the population in general would be properly informed about nanotechnology. About two dozen research projects funded by the Swiss National Science Foundation have been or are running to investigate the hazards implied by the deployment of nanomaterials.

The web platform

The Nano-Cube web platform offers, in addition, a great variety of information about seven different aspects of nanotechnology: fundamentals; applications and products; science and research; commercial and economic aspects; safety and risk; technology and society; and the daily professional life and environment of a nanotechnologist. The texts are composed in order to facilitate teaching staff acquiring an overview of the topic in the shortest possible time. Whoever wishes to know more will find portals to further information, including web links, for all seven topics.

In parallel to the web platform, Nano-Cube also offers "TeachNano": continuous professional development courses aimed at teaching staff; those who take the courses are able to broaden their professional knowledge and with the help of simple applications examples and experiments will familiarize themselves with nanotechnology. These courses take place in St Gallen and elsewhere.

In 2003–2005 the EHB, collaborating with the "Secondary Level II" Institute of the pedagogical university (i.e., the teacher training college, Pädagogische Hochschule, PH) in Berne, undertook the "Nano-4-Schools" project (nanotechnology for vocational training). The project owns its own atomic force microscope (AFM), which, together with a set of suitable samples for measurement, is available on loan to interested schools.[6]

The Nano-Cube project is continuously evolving, ensuring that it keeps up with the rapid pace of development of nanotechnology. One measure of its success has been the great demand for its offerings (the website and the courses). The project's existence demonstrates that it is insufficient to only support nano-research in world-leading laboratories in the federal institutes of technology and the cantonal universities (as is already being done, not least through very active federal programmes such as "Nano-Tera"); the tangible introduction of nanotechnology into society, which can thereby benefit, not least because due regard is paid to the important matters of hazards and safety, requires the active participation and education of the entire community of technical professionals involved in shaping our everyday environment. As a by-product, but a very useful one, the general public can also make good use of the information available, especially via the website, which helps to ensure that no citizen needs to feel that they are being asked to accept something unknown and (by definition, considering that we are talking about the nanoscale) unseen. Without such efforts to involve all of society, the researchers will simply become isolated and there is likely to be constant difficulty in deploying the fruits of their labours, however "technically sweet" (to recall a phrase of J. Robert Oppenheimer) they may be.

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[6] www.nanoforschools.ch