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Nanotechnology and the Modern School**Zaur Gamishidze**

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Abstract: The advancement of human civilization is closely tied to the development of new materials, and the modern era is the era of nanomaterials, which - owing to their unique physical and chemical properties - are capable of radically transforming today's world. Although nanotechnologies have already found practical application across many fields, for most people they still belong to the realm of science fiction. Their significance will only grow: the research and development they demand, and the search for new areas of application, will fall to today's schoolchildren. An essential precondition for this is the intensified integration of the foundations of nanotechnological science into school and university curricula. Nanotechnology is a particularly challenging subject to teach. It is not a traditional discipline but a symbiosis of physics, chemistry, biology, mathematics, engineering, and technology. Even so, it represents a promising field that fosters students' interest in the natural and technical sciences, and teachers of these sciences are best placed to awaken that interest among beginners. The aim of this work is to overcome the psychological barrier that hinders the broad preparation of children to comprehend nanotechnology, guided by the premise that the future belongs to it. The paper discusses classroom activities designed to help students understand nanotechnology and prepare for further study, so that they may become well-rounded, creative professionals. The arguments offered here are necessarily brief; fuller treatment is left to future work.

Keywords: Nanotechnology, Natural sciences, Science education, Educational programs, Quantum concepts.

Introduction

The development of human civilization has always been bound up with the development of new materials. The first materials that humans mastered were wood and stone; the tools for labor and hunting fashioned from them allowed people to survive in a wild, primeval world. Later, humans learned to smelt and work copper and bronze: implements of labor and hunting grew more refined, and man became "master" of the surrounding world. The mastery of iron enabled humankind to create and develop industry and to make an enormous leap forward in its development. The modern era is the era of nanomaterials, which, owing to their unique physical properties, are capable of radically transforming today's world. After all, "whoever is first to master nanotechnology will take the leading place in the 'technosphere' of the twenty-first century."

Throughout the world, nanotechnology is rightly regarded as the technology of the twenty-first century (Ratner & Ratner, 2003). The possibilities for its multifaceted application in science, engineering, industry, healthcare, everyday life, and many other domains offer enormous potential for growth (Roco, 2001). The use of nanotechnologies will make it possible to economize on raw materials and energy consumption and to reduce atmospheric emissions, thereby contributing to the successful development of industry.

Although nanotechnologies have already found application in a variety of fields, for most people they still belong to the realm of science fiction. The importance of nanotechnology will only grow in the future (Ma, 2022; Ramos Torres & Invernizzi, 2024). This will generate interest in the relevant specialized fields and will stimulate research and development work, as well as the search for new areas of application - work that will be carried out in the future by today's schoolchildren. An essential precondition for the successful realization of this process is the intensified integration of the foundations of nanotechnological science into school and university curricula (Roco,

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2003; Srinivas, 2014), which will help reduce the persistent shortage of young specialists in the field. Among all school teachers, it is we - the teachers of the natural sciences - who are best placed to address this problem by awakening an interest in nanotechnology among students just beginning to study the relevant subjects.

Method

Nanotechnology is a particularly challenging subject to teach. It is not a traditional discipline but a symbiosis of physics, chemistry, biology, mathematics, engineering, and technology (Hingant & Albe, 2010; Jones et al., 2013). Nevertheless, for school students nanotechnology represents a promising field, one that stimulates interest in the study of the natural and technical sciences (Hutchinson et al., 2011). Introducing an instructional module entitled "Introduction to Nanotechnology" into the school physics, chemistry, and biology programs would make it possible to develop an educational strategy and concept for schools built around innovative nanotechnology topics, and would familiarize students and teachers with contemporary nanotechnology concepts and curricular materials (Quirola et al., 2018; Schank et al., 2009; Senocak et al., 2021).

In the longer term, this would allow career orientation to be embedded in the educational process as a motivational factor - a mechanism for forming a pool of qualified personnel for the high-technology sectors of the economy, including those in which nanotechnologies are applied. Such an approach would ensure the continuity of professional education along the school-university pathway and would narrow the existing gap between the curricula and programs involved in training specialists in nanotechnology.

The introduction of supplementary units into the physics, chemistry, and biology curricula would help to structure the highly contradictory and unsystematic notions of nanotechnology currently held by school students, by prospective applicants to higher education programs in nanotechnology, and by secondary school teachers themselves (Blonder, 2010), thereby substantially accelerating the development of students' education in the natural sciences.

Results and Discussion

The study of the foundations of nanotechnology, a field at the forefront of modern science, is an important means of stimulating students' acquisition of meta-subject (cross-disciplinary) skills and habits (Laherto, 2010; Schank et al., 2007). This is especially relevant during the transition from a school built on the "knowledge" paradigm to one built on the "activity" paradigm (National Research Council, 2012): it motivates independent work in the natural sciences and develops structured thinking and the ability to formulate hypotheses.

In this regard, promising avenues for collaboration include the following: the problems of training personnel for new professions and specializations in the natural sciences; the introduction of the components of a "macroworld-microworld-nanoworld" educational and methodological complex into the everyday practice of secondary educational institutions; and familiarization with the specifics of conducting a pedagogical experiment to test the developed educational and methodological complex, whose purpose is the integration of knowledge from high technology and the natural science subjects.

The idea that nanotechnology should be taught in schools may strike some as a curiosity. Nevertheless, the central thesis of this paper is that the training of nanotechnology specialists must begin at school (Healy, 2009). First and foremost, we must overcome the psychological barrier that prevents us from setting about the broad preparation of children for the comprehension of nanotechnology.

The school is a rather conservative institution: everything new and complex finds its way to teacher and student only with difficulty. Yet we must be guided by the premise that the future is inevitable - and that the future belongs to nanotechnology. Below I consider the activities that, in my view, should help school students understand nanotechnology and prepare for further study in the field, so that they may become fully fledged, creative professionals. The arguments and comments offered here are necessarily brief; a fuller treatment of the issues raised is left to future work.

1. Changes to school curricula are desirable. Contrary to the current trend, the number of hours allocated to physics should be increased, not reduced. Physics is a worldview-shaping science, and knowledge of its foundations is essential for students of technical and humanities specializations alike, however much the latter may be inclined to disregard it.

2. At the same time, the emphasis in physics teaching should shift away from Newtonian mechanics, the electromagnetism of Ampère and Faraday, geometrical optics, and the like, toward modern physics - in particular, atomic physics and the foundations of quantum mechanics (Yonai & Blonder, 2020). For example, maximum attention should be devoted to the branch of physics that provides the basis for understanding nanotechnology: molecular-kinetic theory.
3. Historicism in the teaching of physics should be abandoned. There is no time to examine the concepts and laws of classical physics in detail or to analyze them in their historical context. This by no means implies that these parts of physics should be neglected; rather, they should be studied axiomatically. For example, the definitions of velocity, acceleration, mass, momentum, and force, together with the formulation of Newton's laws, can be given without any attempt to derive those laws; students should then be taught to apply them in solving problems, in laboratory work, and in real life. Another example: the study of the photoelectric effect should begin with Einstein's equation rather than with the laws of the photoelectric effect, since Einstein's equation is the law of conservation of energy - a foundation of physics - whereas the laws themselves are mere phenomenology, a description of the effect. Such an approach would save time and remove some of the difficulties associated with "understanding" physics.
4. Since the interaction of atoms is governed by the laws of quantum mechanics, to which there is no alternative, sustained efforts are needed to begin "implanting" quantum concepts in students' minds from their school years onward. These include the probability of finding a particle, the wave function, the harmonic oscillator, the photon, and many others. The principal difficulty here is that the quantum properties of particles are frequently at odds with common sense - that is, with our habitual system of notions (Tretter, 2015). As the saying goes, everyone clings to their common sense with both hands and is reluctant to believe that things happen otherwise than they suppose. Yet it is precisely in school students, while they are still very young, that a quantum view of the world can still be formed (Dorouka & Kalogiannakis, 2024).
5. In the teaching of chemistry, considerably more attention should be paid to the mechanisms of chemical reactions. Correspondingly, in the teaching of biology the emphasis should fall on its molecular aspects (protein synthesis, photosynthesis, DNA replication, and so on).
6. In the teaching of mathematics, it is essential to emphasize such concepts as vectors, derivatives, integrals, probability, logarithms, and exponential functions. Students should acquire the ability to work with very large and very small numbers, and should master the elements of combinatorics, mathematical logic, and discrete mathematics.
7. In the teaching of computer science, programming should be taught with a view to modeling physical, chemical, and biological processes, with particular attention to the specific features of their molecular aspects.
8. Far greater opportunities for drawing attention to nanotechnology exist within the system of supplementary (extracurricular) education than within the school curriculum itself (Curreli & Rakich, 2020). Lectures should cover the relevant parts of physics, mathematics, chemistry, biology, and computer science, together with a course entitled "Introduction to Nanotechnology." In school clubs, the project-based format that has recently gained popularity can be oriented toward nanotechnology (Blonder & Dinur, 2011). Although genuine experiments are impossible in this setting, collecting and processing information on nanotechnology, reviewing and summarizing articles on relevant topics, and carrying out physical and virtual modeling - including the modeling of nanodevices and nanosystems - are all well within school students' capabilities (Kottegoda et al., 2022). Olympiad problem sets should include questions on nanotechnology, and dedicated olympiads on nanotechnology topics could also be organized.
9. Since, as already noted, nanotechnology demands synthetic, integrated knowledge, the isolated efforts of individual teachers of physics, chemistry, biology, mathematics, and computer science in this field will be of limited effect. What is required is the joint effort of all: a community of teachers of different subjects, united by the cause of promoting nanotechnology, should be created (Sgouros & Stavrou, 2019). Naturally, this community of teachers should in turn give rise to a community of students captivated by the same idea.
10. It would be unrealistic to expect school education to impart specific knowledge in the field of nanotechnology. The most important things a school can do are to acquaint students with the current state of nanotechnology and to actively promote nanotechnological ideas (Greenberg, 2009; Toth & Jackson, 2012). Agitation and propaganda are concepts that have often carried a dubious reputation; in this case, however, they should yield the desired result: motivated school graduates will become university students, obtain the appropriate higher education, and embark on creative work in the field of nanotechnology.

Conclusion

The forms of school work in the field of nanotechnology proposed here are, admittedly, preliminary and promotional in character. What matters is that this work begin without delay; the concrete work itself will then assume definite forms and yield its first results. Direct hands-on activity in nanotechnology is impossible in

schools owing to the extreme complexity of the experimental equipment (Brazell et al., 2009; Jones et al., 2020), and this complicates work with children for whom visual clarity and demonstration are essential.

A solution to this problem could be the creation of demonstration and training centers within large research institutions engaged in nanotechnology, to which groups of talented students could be sent for a certain period to gain first-hand experience of nanotechnologies. It must be emphasized once again that work in schools should be carried out by a team of like-minded individuals “charged” with nanotechnological ideas. At the same time, young teachers are afforded an excellent opportunity to distinguish themselves in this new and highly important field.

Recommendations

Research will continue in the direction of introducing and teaching nanotechnology at various educational levels (Tretter, 2020; Yu & Jen, 2020), using the method mentioned in the article as well as other methods.

Scientific Ethics Declaration

* The author declares that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the author.

Conflict of Interest

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