Nanothinking as an educational concept of the 21st century

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Abstract. Around the world, the pace, complexity and social significance of technological changes have been increasing. Striking developments in such areas as computer and communications technology, biotechnology and nanotechnology are finding applications and producing far-reaching effects in all spheres of business, government, society and the environment. However, the far-reaching social consequences are often not understood until after new technologies become entrenched. Historically this has resulted in important lost opportunities, significant social and environmental costs and channeling societal development down long-term unhealthy paths.

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Introduction

One decade into the 21st century, people and governments worldwide face decisions on daily basis involving complex scientific considerations or innovations in technology. Decisions small and large – whether they are policy-makers' votes on a climate bill, biotech corporations' considerations of potential product lines, consumers' choices of food purchases or educators' use of computers in the classroom – must incorporate a dizzying array of factors. The new participative democracy demands that citizens be asked to make judgments, and even vote, on subjects about which they know very little – the desirability of cloning animals and human beings, creating novel biological organisms, manipulating matter at an atomic scale, nuking your enemies, eugenics, genetic engineering (GE), genetically modified (GM) foods, nano-products, and other great moral and economic questions of the day. Therefore, educational systems have to produce a steep increase in citizens' intellectual potential in order to provide sane answers to such deep philosophical questions, previously the domain of university researchers.

Educational environment is becoming a new supercomplex system with a constantly changing intellectual pattern. It has been predicted that today's school-leavers will have many careers – not just jobs, over their lifetimes, and that more than 50 % of the jobs they will be doing do not yet exist. But one thing is certain – they will be knowledge jobs, intellectually more demanding and almost certainly involving interaction with technologies far more sophisticated than those existing at present. Mindpower is replacing manpower.

Still, the structure of our universities has changed very little in the past fifty years; they are still organized in the traditional fields with little or no horizontal structures. In materials science, as in many other fields, much of the most exciting discovery potential is located at the boundaries between traditional disciplines. Already today, many novel multifunctional nanomaterials, advanced nanodevices, new nano-based products and processes are designed and developed by team efforts of materials scientists working with chemists, biologists, physicists, information technology experts, and engineers. It is thus apparent that we need to create new types of universities, so called virtual universities, which have 'departments without walls' [1-3].

1. Nanotechnology as the imperative for educational redesign

Rapid technological changes have dramatically altered our educational needs. The simplest explanation for the current need of educational change is that we, as society, have outgrown our educational systems disseminating core knowledge and building basic skills. With the advent of the information age, and now the beginning of new technologies age, the educational model of today no longer meets our societal needs. In fact, it is limiting the ability of teachers and students to adapt to the 21st century.

Nanotechnology is an exciting area of scientific research and development that is truly multidisciplinary. Nanotechnology originates from the Greek word *nano* which means *dwarf*. A nanometer is one billionth (10^{-9}) part of a meter, which is tiny, only the length of ten hydrogen atoms, or about one hundred thousandth of the width of a hair!

Nanotechnology is not really anything new. In one sense, it is the natural continuation of the miniaturization revolution that we have witnessed over the last decade.

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It is necessary to point out that millionth of a meter (10^{-6} m) tolerances in engineered products have become commonplace. A good example of the application of nanotechnology is a mobile phone, which has changed dramatically in a few years – becoming smaller and smaller, while paradoxically growing cleverer and faster – and cheaper!

What is new, though, is the multidisciplinary approach and the ability to 'see' these entities and to manage them. Although scientists have manipulated matter at the nanoscale for centuries, calling it physics or chemistry, it was not until a new generation of microscopes were invented in the late 1980s in IBM, Switzerland that the world of atoms and molecules could be visualized and managed. Now biologists can discuss steric effects of cell membranes with chemists, while physicists provide the tools to watch the interaction *in vivo* - infrared (IR) microscopes to study molecular systems up to single molecules and and X-ray microscopes to study atomic structures and to handle even single atoms.

In simple terms, *Nanoscience* can be defined as the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, in order to understand and exploit properties that differ significantly from those on a larger scale. It is not really a new field, but a different way of looking at all fields. Its development will require the expertise of all scientists – from engineers to ecologists. *Nanotechnology* can be defined as design, engineering, production and application of structures, devices and systems by controlling shape and size at a nanometer scale..

A concise definition is given by the US National Nanotechnology Initiative: 'Nanotechnology is concerned with materials and systems whose structures and components exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes due to their nanoscale size. The goal is to exploit these properties by gaining control of structures and devices at atomic, molecular and supramolecular levels and to learn to efficiently manufacture and use these devices' [4]. This term can be applied to many areas of research and development – from medicine to manufacturing, to renewable energy, transport, computing, and even to textiles and cosmetics.

At the nanoscale, the properties of a material may change. For example, hardness, electrical conductivity, thermal conductivity, colour or chemical reactivity of minuscule particles of materials are related to the diameter of the particle. They demonstrate new and unusual properties that are not obvious in the bulk material.

This is because a nanoparticle has a large surface area in relation to its size, and is consequently highly reactive. This is exemplified by the fine grained materials that we use in our daily lives, such as flour, which can become explosive in some circumstances.

Specific functionalities, therefore, can be achieved by reducing the size of the particles to $1\div100$ nm. Particles at the nanoscale are below the wavelength of visible light, and therefore cannot be seen. It can be difficult to think of and imagine exactly the invisible world of atoms and molecules to get a greater understanding of how it will affect our lives and the everyday objects around us.

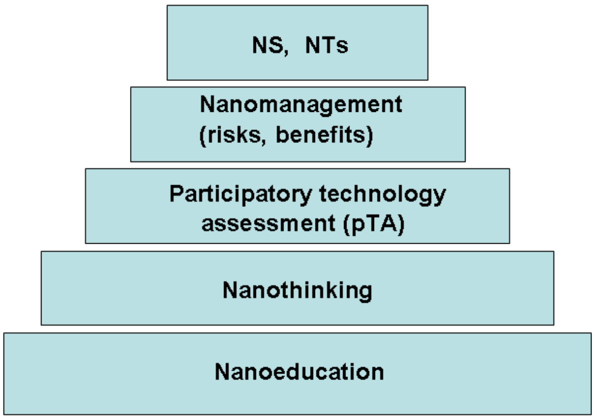

Fig. 1. Nanochallenges hierarchy.

But the areas where nanotechnologies are set to make a difference are expanding alongside with the challenges they pose to society. Challenges in nanotechnologies can be presented in their hierarchical priorities (Fig.1).

Nanochallenges comprise such basic areas as: i) nanoeducation; ii) nanothinking; iii) participatory technology assessment (pTA); iv) nanomanagement (incorporating risks and benefits).

2. Nanoeducation

During the past 10 years, we have seeded many ideas into the global consciousness to stimulate preparing our students for their future. The world is changing but our education matrix remains in the Industrial version of reality. We are not even close to understanding, nor preparing our students for these major changes they will face in the next few decades. *Nanoeducation* - is the new foundation for a new way of thinking, for the integration of all disciplines to expand our next generation students' knowledge base and prepare them for a very different future in a global society enhanced by all of the integrated science research now in process.

The rise of a highly networked global knowledge economy is changing the interface between scientists, researchers and the general public as consumers of new technologies, new materials and devices. Nanoeducation has to contribute to closing the gap between public rhetorical value and nanotechnologies practice on decision-making policy.

Many companies throughout Europe and the world report problems in recruiting the types of graduates they need, as many graduates lack the skills to work in a modern economy. For Europe to continue to compete alongside prestigious international institutions and programmes on nanomaterials, it is important to create educational institutions which would provide a top-level education and the relevant skills mix and would cover education, training, sciences and technologies for research and have strong involvement by European industry. The elements for such a high level education are supposed to be as following:

i) multi-disciplinary skills;
ii) top expertise in nanomaterials science and engineering;
iii) literacy in complementary fields (physics, chemistry, biology);
iv) exposure to advanced research projects;
v) literacy in key technological aspects; exposure to real technological problems;
vi) basic knowledge in social sciences, culture, management, ethics, foreign languages;
vii) literacy in neighbouring disciplines: international business, law, IT, etc;
viii) interlinkages between education, research and industrial innovation: students will be ready for what research and development will provide;
ix) sharing of post-docs, PhD and MS (masters) students to foster the mobility of permanent researchers and professors between different institutions to create 'team spirit'.

Companies, universities, governments, research organizations and technical societies must all strive to define their roles in this partnership. The 'output' will be graduates with a new way of thinking, skillful manipulators, synthesizers and creators of new knowledge excellently equipped to solve future complex problems and to work collaboratively.

3. Nanothinking

Data saturation that accompanies the 'new technologies age' has fostered an ever-increasing interdependency between people. The pace of expected adaptation is accelerated to a pace that exceeds individuals' abilities to accommodate. Being on the receiving end of technologies deluge serves to undermine people's confidence and sense of personal responsibility giving rise to the sense of helplessness that many people feel as the world enters the 'age of interdependency'. Nanothinking can serve as the antidote to the sense of helplessness since it is a concept for seeing the 'structures' that underlie complex processes, for a much better understanding how our organism works, and for discerning how to foster health, safety and the surrounding environment. If we do not understand ourselves, we will not be able to change our life for the better.

Nanothinking is a comprehensive systems thinking which offers a language that begins by restructuring the way how we think. It is a dynamic concept where practitioners continually engage in a process of 'seeing wholes' – a perspective that pays attention to the interrelationships and patterns of influence between constituent parts to foster the dissolution of compartmentalization of science and the corresponding compartmentalization of the mind. Nanothinking can be defined as the understanding of a nanophenomenon within the context of a larger whole. *To think nanoscalely* – means to put things into a nanoscale context and to establish the nature of their relationships.

Contemporary top-level education envisions causing students think systemically – integrating not only macro-, micro- but also the nano- scale. Nanothinking can be defined as 'visualizing matter, structures and processes at the nanoscale'.

Public thinking can be formed and improved through sustained and carefully crafted dialogue, which has to be integrated into educational communication practice. Educational communication has to contribute to developing a new way of thinking – the systemic thinking, with the main strategy – 'how to think' rather than 'what to think'. It is the privilege of a liberal university not to give the right answers to students but to put the right questions.

Educational communication, as human communication in general, can be defined (according to a German sociologist Niklas Luhman) in terms of interactive construction of meaning/thinking. Thus, it can be presented as the unity of three components:

i) *information* - provided by teachers possessing knowledge;
ii) *utterance* - by means of language;
iii) *understanding* - a kind of created 'identical' thinking.

To this unity is added the acceptance or rejection of the receiver to continue communication and interaction (Fig. 2).

Anthony Giddens, a famous British sociologist, points out that people are always to some extent knowledgeable about what they are doing. Because people are reflexive and monitor the ongoing flow of information, activities, and conditions, they adapt their actions/ways of thinking to their evolving understanding.

As a result, knowledge changes human activities/ways of thinking, thus, shaping our consciousness (Fig.3). Language, in this respect, can act as a constraint on action/way of thinking, but at the same time, it also enables action by providing common frames of mutual understanding [1].

Consciousness is not inherited or static. It rather becomes a reflective project - an endeavour, which we continuously work out and reflect on. It is not a set of observable characteristics of a moment, but becomes an account of a person's life.

4. Participatory technology assessment (pTA)

The development of a new way of thinking envisions bringing the practice of *participatory technology assessment* (pTA) into alignment with the realities of the 21st century technology – to create a 21st century educational model.

The ability to create novel biological organisms, manipulate matter at an atomic scale, or intervene significantly (and possibly irreversibly) in the earth's climate system raises a host of ethical, social, legal and environmental questions that will require broad public discourse and debate.

Scientists and researchers engaged in nanoscience and nanotechnology research and development constitute a relati-

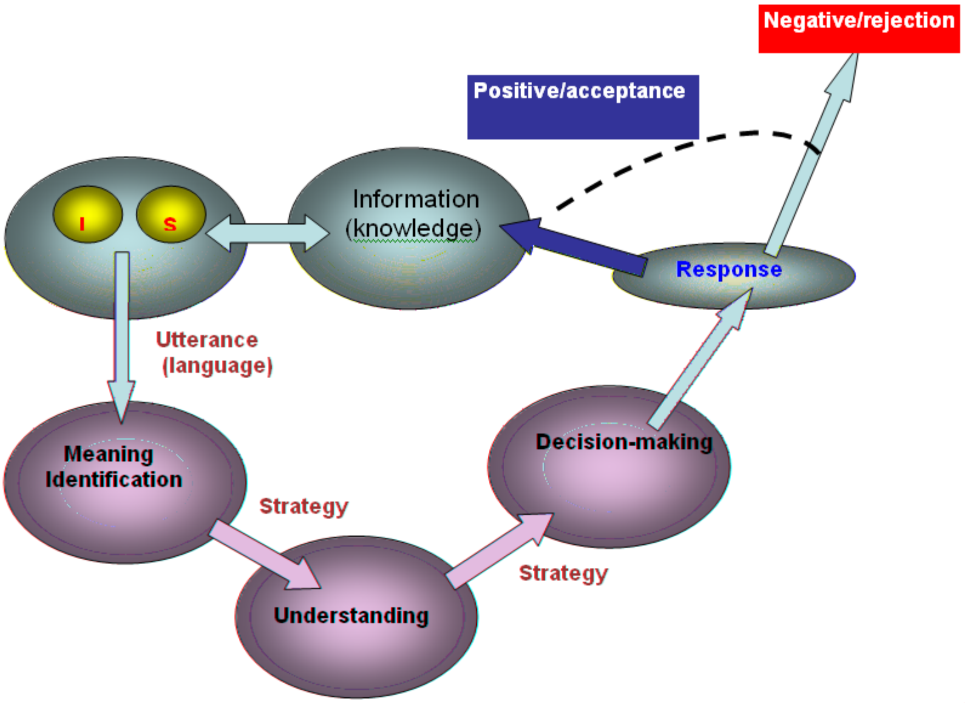

Fig. 2. Language and understanding as major determinants for shaping consciousness.

vely small group compared to the general public. However, the outcome of their work – innovative materials, devices and technologies have a strong impact on the life of the whole human society.

Nanotechnology applications are being developed in nearly every industry, including electronics and magnetics, energy production and storage, information technology, materials development, transportation, medicine and health. There are currently more than 600 consumer nano-products incorporating engineered nanoparticles on the market including food and beverages, dental fillers, toothpaste, optics, electronics, clothing, wound dressings, sporting goods, dietary supplements, and cosmetics.

In the future, mechanical ‘microbes’ injected into an organism may be able to combat disease-causing bacteria and viruses, remove cancerous cells or dispense medicines. Microscopic robots may be able repair, or even assemble complex devices or remove harmful substances from the environment.

Technology assessment (TA) is a practice intended to enhance societal understanding of the broad implications of science and technology. This creates the possibility for citizens of the world of preparing for – or constructively influencing – developments to ensure better outcomes.

Participatory technology assessment (pTA) enables the general public/laypeople, who are otherwise minimally represented in the politics of science and technology, to develop and express informed judgments concerning complex topics, as well as, to make informed choices.

Since applications of nanotechnology will quickly penetrate all sectors of life and affect our social, economical, ethical and ecological activities, the general public’s acceptance is compulsory for further developments in the field of nanotechnology and its applications. This acceptance will be influenced by the low level of public awareness of many innovations in science, and especially, in nanotechnology. This is mainly due to the unpredictability of their properties at the nanoscale and the fragile public confidence in technological innovation and regulatory systems.

Consequently, it is of the utmost importance to educate the public, and to disseminate the results of nanotechnology development in an accurate and open way so that the general public will eventually transform their way of thinking to accept nanotechnology. In this endeavour, educational institutions have a pivotal role in developing pTA practices by following factors:

i) educating public (pupils, students) about science and technology;
ii) informing the public about the benefits and risks of nanomaterials and nanoproducts;
iii) evaluating, minimising, and eliminating risks associated with the manufacturing and use of nanomaterials and nanotechnology enabled products (risk assessment);
iv) exchanging with public authorities for the risk management of nanotechnologies.

In the process, pTA deepens the social and ethical analysis of technology, complementing the expert-analytic and stakeholder-advised approaches. The Internet and interactive TV capabilities can help pTA be more effective and cost-efficient and would also align with the policy-makers’ initiatives to make them more transparent, accessible and responsive to popular concerns.

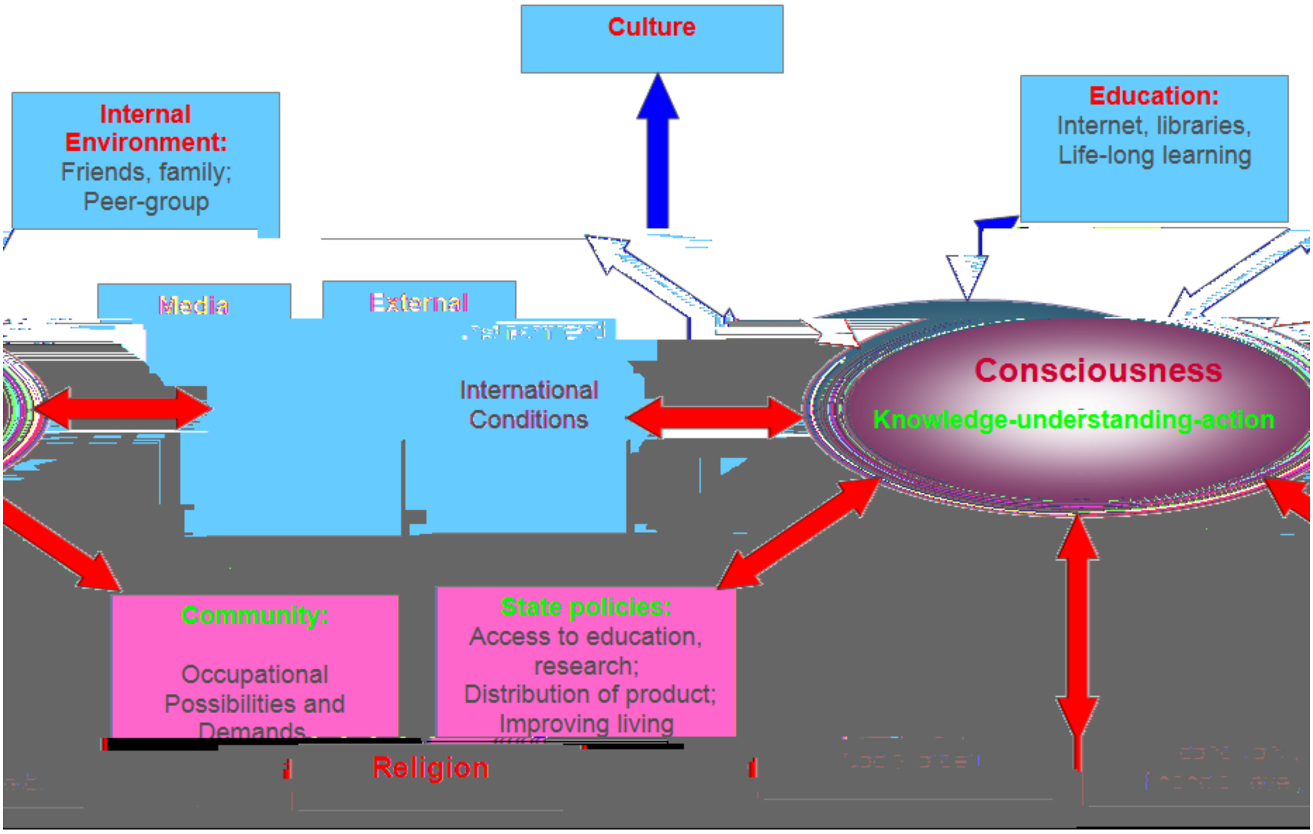

Fig. 3. Factors influencing consciousness development.

5. Nanomanagement

Nanotechnology is a radically new approach to manufacturing. It will affect so many sectors that failure to respond to the challenges will threaten the future competitiveness of a large part of the economy.

As nanotechnology has emerged from the laboratory into industrial manufacture and commercial distribution, the potential for human and environmental exposure, and hence risk, has become both reality and priority.

The research into health, safety and the environmental implications of nanotechnology lacks strategic direction and coordination. As a result, researchers are unsure about how to work safely with new nanomaterials, nano-businesses are uncertain about how to develop safe products, and public confidence in the emerging applications is in danger of being undermined.

Nanotechnology presents both an unprecedented challenge and unparalleled opportunity for risk management. Existing risk management principles are inadequate, given pervasive uncertainties about risks, benefits and future directions of this rapidly evolving set of technologies. The health implications of nanoparticles are unknown, the ramifications may be profound, and only a lengthy and extensive research effort can assess the safety implications with any certainty.

Yet the public, driven by heuristics such as *Affect and Availability*, is likely to stigmatize and reject this technology unless effective and credible risk management processes can be put into practice quickly. Because traditional command and control regulation will be unable to fill this need, innovative approaches that are incremental, flexible and decentralized should be developed to fill the risk management gap.

Scientific and technological innovation now requires accompanying innovations in management mechanisms that place an emphasis on public engagement. In its turn, public policy has to be grounded on understanding the risks and benefits of new technologies to have practical impact on decision-making.

One of the most pertinent examples of a multi-stakeholder approach to voluntary nanotechnology regulation is the Foresight Institute, which was organized explicitly to provide a forum for public discussion of the risks and benefits of nanotechnology and to ‘pave the way’ for its societal acceptance. Institute members include scientists, engineers, business people, investors, ethicists, policy makers and lay people as well as firms. Thus, the organization represents a broad spectrum of stakeholders, interests and opinions to be at the forefront of public discussions of nanotechnology risks and benefits [2].

Some engineered nanoparticles, including carbon nanotubes (CNT), although offering tremendous opportunities also may pose risks which have to be addressed sensibly in order that the full benefits can be realized. We have all already learned how to handle electricity, gas, steam and even cars, aeroplanes and mobile phones in a safe manner because we need their benefits.

The same goes for engineered nanoparticles. Mostly they will be perfectly safe, embedded within other materials, such as polymers. There is some possibility that free nanoparticles of a specific length scales may pose health threats if inhaled, particularly at the manufacturing stage. Industry and government are very conscious of this, are funding research into identifying particles that may pose a hazard to health or the environment, and how these risks may be quantified, and minimized over the whole lifecycle of a given nanoparticle.

There is no doubt that nanotechnology has great potential to bring benefits to society over a wide range of applications, but it is recognized that care has to be taken to ensure these advances come about in as safe a manner as possible.

We need to manage nanotechnologies making our life more intellectual, comfortable and safe.

6. Bringing the spirit of nanotechnology into the classroom: Pilot study

With the aforementioned in mind, we launched a pilot study at Information Systems Management Institute (ISMA, Riga, Latvia) in different groups of students comprising Information Technologies, Management, Tourism, and Design departments as well as international students enrolled in ISMA on the ERASMUS student exchange programme.

We have undertaken a set of researches into the nature of students' intellectual potential development in order to elicit their general knowledge of some basic scientific notions and their understanding of the utilitarian value of some scientific phenomena. The study envisioned providing the necessary knowledge, understanding and support to our students to be successfully introduced to the technologically empowered environment of today's life, to adjust and adapt in it.

The purpose of the pilot study was primarily to work with the delivery of the questionnaires and interview questions to determine what was required to elicit the quantity and quality of data needed to respond powerfully to the research question. As a result of four pilot undertakings – a fluid conversation with students, an interview, a questionnaire with a feedback analysis – a level of intimacy and trust was created that supported the gathering of quantity and quality data.

Our mission has a focus on introducing nano science curriculum into classrooms. In order to encourage students and teachers to understand the importance of this scale of science, they need to see that *size matters* in the unseen world of nature. This introduction to the *unseen size of nature* can stimulate curiosity and a desire to learn more about their world through study with advanced microscopes that lead to an interest in chemistry, biology, physics, information technologies and other sciences.

The results of the study make us conclude that students' general knowledge of basic disciplines is rather restricted, sometimes rather obscure or fluid. What is more discouraging, the research has established that students do not possess the systemic vision of the sciences and the world. Their knowledge is compartmentalized – they are unable to relate physics to chemistry, to biology, etc. Hence is their low level of awareness of many innovations in science, and especially, in developments in the field of nanotechnology and its applications. This is mainly due to the inability to imagine the world at the nanoscale level. Hence is the fragile confidence in technological innovation and regulatory systems.

There might be objective and subjective reasons for the situation observed. Most higher education teachers feel that the knowledge students gain at secondary school is not sufficient for a higher education institution. But most importantly, our educational programs are structured in the way that perpetuates the myth that knowledge exists in separate compartments, as if there were no relationship between physics, chemistry, biology; between language and literature, and art, and history, and in so doing, encourages a similar compartmentalization of the mind. At the same time, the main problem area mentioned concerns the link between theoretical knowledge and students' envisioning their utilitarian value.

In any case, this is an alarming signal, which demands a critical analysis of the adequacy of the educational materials, the methods of teaching and research and other components of the educational practice.

Conclusions

The European context is a stage for developing new relationships, new ideas, new discoveries and new people. It is the stage for European-wide educational and scientific exchange and success for those individuals who can engage their intellectual and emotional potentials in scientific research and development, talents for openness and flexibility in order to exchange innovative thoughts, ideas, approaches and strategies.

This research is not attempting to solve the problem. The intent is to highlight the possibilities available through systemic, integral education to shape up and manage students' intellectual potential development, which offers a powerful philosophical, theoretical and practical approach to educating new generation specialists capable of providing the solutions to many long-standing medical, social and environmental problems. These ideas are all leading to what is termed 'disruptive' solutions, when the old ways of making things are completely overtaken and discarded. New solutions demand new ways of thinking.

The new paradigm of contemporary technologically advanced society brings to the agenda a new paradigm of higher education. This new paradigm envisages that higher education practitioners become pluriskilled, transdisciplinary mediatots promoting constructive solutions to innovative unprecedented problems of the day.

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