No Walls, No Ceilings, No Floors: Nanotechnology and Some Implications for Education

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Abstract: Nanotechnology is an enabling technology that is poised to create a huge impact in the various spheres of human concerns such as the geopolitical, business, education, legal, military, environment, health, and medical domains. With its rapid and inevitable development, it becomes imperative not only to deliberate on its ethical and social implications but likewise examine the ontological and epistemological issues and difficulties underlying this fledgling field. This paper will explore the novelty, distinctiveness, interdisciplinarity, and incommensurability issues in nanotechnology. More specifically, it will center on the uniqueness of the field as it delves into the claims regarding dissolution of borders and boundaries in the sciences, risk, complexity, and uncertainty factors and selected foundational issues in nanotechnology. It shall examine how the perceived melting of boundaries, unforeseen horizons, and the lack of a stable foundation in nanotechnology will pose some challenges and opportunities to education and research particularly in science, engineering, and the humanities.

Keywords: *nanotechnology, education, interdisciplinarity, uncertainty and risks, foundational issues*

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Introduction

Despite our advanced technological age, a great magnitude of problems continues to plague us in the 21st century. Poverty, global health crises, climate change, threats to human security, energy crisis, environmental degradation, and a host of other problems remain unsolved. In recent years, a great deal of discussion about nanotechnology has surfaced. Could it be the long awaited panacea that will eventually solve the crises of our times?

Nanotechnology is often cited as the tool that will dramatically change the future. Much of the earlier discussion on this subject was generated by hype. However, the increasing amount of current literature on nanotechnology indicates that the elevated level of discussion of this discourse has moved on from what was considered as merely as hype. Nanotechnology is replete with philosophical issues such as novelty, distinctiveness, interdisciplinarity, and incommensurability issues, blurring boundaries between nature and artifact, and uncertainty and risks issues which provide a fertile ground for mentally stimulating discussions. Knowing these issues will help us understand the complex nature of nanotechnology and its impact on education.

On the Novelty and Distinctiveness of Nanotechnology

It is natural for people to get excited at the prospect of something new and unique. Novelty offers a myriad of promises and expectations and distinctiveness excite our imagination to see beyond the trivial and the commonplace. Such attributes are often exploited for commercial purposes, embellished with advertising language such as "state- of- the-art," "groundbreaking," "cutting edge," "top of the line," and "world class." In recent years, we witness how the industry, and in particular, start up companies rode the nano waves. A lot of companies made use of the nano-prefix such as NanoInk, Nanomedica, NanoOpto, Nanogap, Nanometrics, Nano-Tex, and so on. Often, the media is identified as the institution responsible for inflating the nano-bubble. Does nanotechnology merit the true meaning of novelty or is it just an old wine in a new flask? To answer this question, I will proceed by examining the issue and citing arguments from the works of Pradeep and Schummer.

Pradeep enumerates some arguments in favor of novelty: 1) transdisciplinary nature of nanotechnology; 2) control and manipulation atoms and molecules; 3) the size of matter being observed; and 4) cost of nanofabrication.

The first argument claims that sciences and technologies –chemistry, physics, biology, mathematics, cognitive sciences, and the life sciences are converging at the nanometer scale, which led to the blurring of traditional boundaries of disciplines.[1] This means that nanotechnology is an incredibly broad field and its applications are limitless. The second point stresses that the core novelty in science and technology on the scale of nanometer is that scientists and technologists do not invent the world *ex vivo*, as in the past, but *de novo* since the new artefacts are made of components which have no natural analogues.[2] Examples abound in the market where self-cleaning windows, stain-free fabrics, scratch-proof paints are made available. The third contention suggests that that nano, as measurement, has unlimited spectrum, since all physical matter, irrespective of its nature, can be measured, and the only condition is that measurement facilities for that size regime should exist.[3] Unlike the traditional way we distinguish and classify science, i.e. as having a material and formal object, nanotechnology makes use of size (of a body) as the only condition for inclusion in its domain. Practically, every physical reality, whether living or non-living, natural or man-made, reduced to the nanometer scale would fall under nanotechnology. The final argument maintains that the manufacturing of nanomaterials does not entail enormous capital outlays for industrial infrastructure that the other technologies require.[4] In contrast to bulk technologies, nanoscientists study very little samples to get results, hence, cost-effective.

On the other hand, Schummer takes the opposite stance and strongly argues that nanotechnology is hardly revolutionary, and sees it as part of continuing research fields. Schummer backed his claims with some historical data in scientific development.

He also cautioned his readers not to fall prey to what he calls *subjective/ objective* fallacy. This fallacy is committed when a person considers a thing as novel only because he/she has never perceived or heard of it before.[5] Nanotechnology is marketed to the general public as a new, revolutionary, and transformative technology. Actually, the prefix "nano" is part of the old scientific nomenclature. However, the novelty rhetoric was used by promoters of this technology to generate public interest largely for commercial purposes.

While Schummer acknowledges that nanoparticles have been known for centuries to be endowed with unique properties that defy the laws of classical physics, he nevertheless admits that the systematic development and large scale commercialization of these particles for specific uses, is something new.

[1] T. Pradeep, *Nano: The Essentials,* (New York: Mc Graw-Hill, 2008), 350-351.

[2] Ibid., 351.

[3] Ibid.

[4] Ibid.

[5] Joachim Schummer, *On the Novelty of Nanotechnology: A Philosophical Essay,* https://pdfs.semanticscholar.org.

Guozhong Cao takes a compromised position from the Pradeep and Schummer, arguing that nanotechnology is new, but research on nanometer scale is not new at all.[6] According to him, the Chinese are known to have used gold nanoparticles as an inorganic dye to introduce red color into their ceramic porcelains more than a thousand years ago and that colloidal gold was, and still, used for treatment of arthritis.[7] Much of what we know today as nanotechnology had been in practice long ago, not as a science but as an art. Cao qualifies the *techné* and technique in nanotechnology which makes it novel, namely, "the ability to see and manipulate matter on the nanoscale and our understanding of atomic scale interactions."[8]

Interdisciplinary Issues in Nanotechnology

There are quite a number of claims that nanotechnology is interdisciplinary. For instance, The Royal Society and the Royal Academy of Engineering hold that nanotechnologies can be regarded as genuinely interdisciplinary, and have prompted the collaboration between researchers in previously disparate areas to share knowledge, tools and techniques.

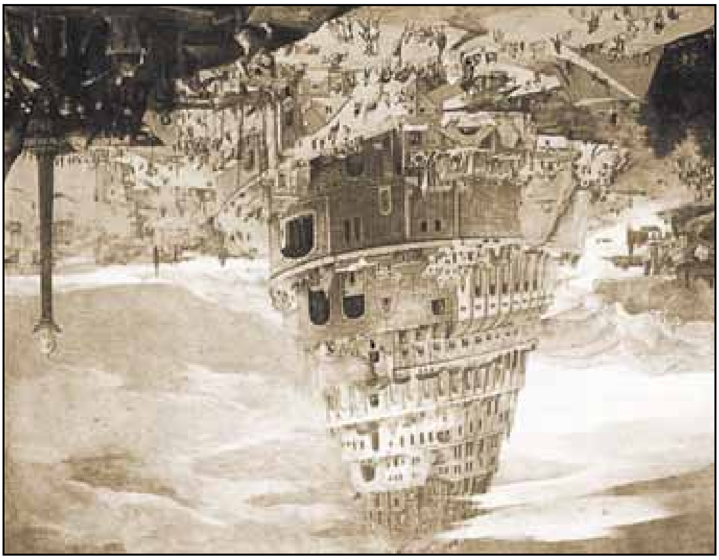
The US National Nanotechnology Initiative emphasized this quality. Interdisciplinarity, networking, partnership, and collaboration are fostered in the US Nanotechnology Investment Strategy, in particular, in two areas: 1)**Long-term fundamental nanoscience and engineering research** will build a fundamental understanding and lead to discoveries of the phenomena, processes, and tools necessary to control and manipulate matter at the nanoscale. This investment will provide sustained support to individual investigators and small groups doing fundamental research, promote university industry-federal laboratory partnerships, and foster interagency collaborations. 2) **Centers and Networks of Excellence** will encourage research networking and shared academic users' facilities. These nanotechnology research centers will play an important role in development and utilization of specific tools, and in promoting partnerships in the coming years.

Lux Capital, a venture capital firm focused on making early stage investments in nanotechnology symbolically captured the idea of "interdisciplinarity" in nanotechnology as upside down Tower of Babel, where thousands of researchers speaking different languages have the common goal of building down to understand the atomic level.

[6] Guozhong Cao. *Nanostructures and Nanomaterials Synthesis and Properties*, (Singapore, Imperial College Press, 2004), 4.

[7] Ibid.

[8] Ibid. Agazzi wrote that *techne* deals with the knowledge of doing or making while technique refers to the component application of a certain know how without necessarily knowing why certain procedures are efficacious. See Evandro Agazzi, *Right, Wrong and Science*, (Amsterdam: Rodopi, 2004), 56.



Nanotech symbolically as upside down tower of Babel
Source: The Nanotech Report 2003 by Lux Capital

Pradeep argues that nanotechnology is a fusion technology and therefore incorporates, for instance, bio and information technologies.[9] The interface of multiple systems will "amplify the complexity and inevitably exceed the hypothetical consequences of one single technology."[10] He further claims that it has the potential for melting the traditional boundaries of natural and human sciences and liberating the various disciplines from their life in isolation. Pradeep extended the notion of interdisciplinarity in the natural sciences to the human sciences. This was the classic distinction between the *Naturwissenschaften* and *Geisteswissenschaften.* In a paper published by Corbet, et al, the interdisciplinary nature of nanotechnology is maintained. These researchers claim that engineers and scientists were confined in their specialization but, as a result of the interdisciplinary nature of nanotechnology, a new breed of scientists, engineers, and even research laboratory has emerged.[11] For Meyer and Kuusi, we can refer to nanotechnology as a *leitbild system* that integrates different approaches, each of which is being autonomous enough to bear its own identity but also depending to a greater or lesser extent on results from other fields.[12]

[9] Pradeep, 352.

[10] Ibid.

[11] J. Corbet, et al, Nanotechnology: International Developments and Emerging Products, accessed at http:wwwsciencedirect.com/science.

[12] *Leitbild* is a German word that illustrates the guiding function of an emerging paradigm. It has twofold functions- as a guide and as an image. See Martin Meyer an Osmo Kuusi. *Nanotechnology: Generalizations in an Interdisciplinary Field of Science and Technology*." *HYLE* 10-2 (2004). Retrieved from http://www.hyle.org/journal/issues/10-2/meyer-kuusi.htm.

Why is the notion of interdisciplinarity crucial in nanotechnology? The synergistic effects of interdisciplinarity will transform technological vision to reality. Gleaned from the Executive Summary of the report on *Societal Implications of Nanoscience and Nanotechnology* (Roco and Bainbridge, 2001), interdisciplinary is the product of having similar object of study (i.e. objects of a nanoscale) and similar vision (i.e. technological progress). At a more superficial level, funding researches of different disciplines would be less cost-effective. As Schummer pointed out, "agencies (referring to federal research-funding agencies) tend to focus on the idiosyncratic academic problems instead of dealing with problems of general societal concern."[13] Hence, the goal of convergence of disciplines is consistent with that of the funding agencies.

While the talk of interdisciplinarity is not considered as an issue as it was generally accepted without further talk, Schummer raised some issues concerning the interdisciplinary nature of nanotechnology. First, he pointed out that nanoscale researches which are based on the size of the objects are too vague to provide an integrative function.[14] More than the size of the objects, it is the disciplinary perspective of the researcher as a chemist, biologist or physicist, that counts.

Secondly, he contends that certain discipline rooted technological paradigms such as 'self-assembly' and atom-by-atom manipulation, which are currently employed in nanotechnological visions, are barriers to interdisciplinarity insofar as they disintegrate rather than integrate the disciplines.[15] For instance, the underlying metaphysical assumption in atom-by-atom manipulation is precision and control. One way of achieving it is through the invention of powerful instruments like scanning probe microscopes that are capable of imaging and moving the atoms at the same time. Another paradigm, which is derived from mechanical engineering, posits a universal assembler, which is designed to create molecular structures from individual atoms by sticking them together with ultra-atomic precision.[16]

Because of the lack of interdisciplinary collaboration among the disciplines, Schummer prefers to use the term nanotechnologies (plural) rather than of one nanotechnology (singular).[17]

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[13] Schummer, *From Nano-convergence to NBIC-Convergence*, 2008, Accessed at http://www.joachimschummer.net/publications.html.

[14] Schummer, Interdisciplinary Issues in Nanoscale Research, 2004, 16, Accessed at http://www.joachimschummer.net/publications.html.

[15] Ibid., 9-10.

[16] Ibid., 17.

[17] Schummer, *The Impact of Nanotechnologies on Developing Countries*, http://www.joachimschummer.net/papers/2007_Nano-Developing-Countries_Althoff-et-al.pdf.

Incommensurability Issues

The concept of incommensurability was popularized by Thomas Kuhn in *The Structure of Scientific Revolutions.*[18] He hinted at three levels of incommensurability-cognitive, conceptual, and methodological. Cognitive incommensurability emerges when there are no common standards to assess the adequacy of certain theories about the phenomena under examination. Conceptual incommensurability is the outcome of the lack of common standards to adjudicate concepts used to describe the phenomena. And methodological incommensurability arises from the lack of common standards of assessment of the relativity of the different methods used. These three forms of incommensurability will be applied to nanotechnology.

Within nanotechnology practitioners, there exist two opposing viewpoints that inevitably result in a clash of disciplinary paradigms. In the scientific community, it is known as the Drexler-Smalley debate.[19] Drexler is a mechanical engineer by profession. Smalley was a chemist. Both are highly esteemed by the scientific community to where they belong.

According to Smalley, "the precise control over the positioning of atoms required by Drexler cannot be achieved, given that the atoms of the manipulator arms will interact with *other* atoms in unintended ways. Just by positioning an atom in a given place is not enough to guarantee that it will interact *only* with the atoms *we* want it to interact with."[20] Drexler's answer was: "Like enzymes and ribosomes, proposed assemblers neither have nor need these Smalley fingers."[21] We cannot assign one or the other as the winner or the loser in the debate precisely because of incommensurability. As Kuhn remarks, "since the vocabularies in which they discuss such situations consist, however predominantly of the same terms, they must be attaching some of those terms to nature differently. And their communication is inevitably only impartial. As a result, the superiority of one theory to another is something that cannot be proved in the debate."[22]

There is no common measure in the way we grasp reality. Drexler adopts a mechanical theory to articulate his concept of molecular assembler. Smalley, on the other hand, appeals to chemical theories, which is why he refused to agree

[18] Thomas Kuhn, *The Structure of Scientific Revolutions,* 3rd ed., (The University of Chicago Press), 1996.

[19] Otavio Bueno, "The Drexler-Smalley Debate on Nanotechnology: Incommensuarability at Work in in Nanotechnology: Challenges and Implications for Philosophy, Ethics and Society, ed. Schummer and Baird, Singapore: World scientific Publishing Co, Pe, Ltd, 2006, 32.

[20] Ibid.

[21] Ibid.

[22] Kuhn, 198.

with Drexler. Each of their theories is adequate in their own sphere of influence. Furthermore, there is no common measure in the way they conceptualize things. In Drexler, the assembler is conceived in mechanical terms. His choice of words such of conveyors, computers, positioning devices, is the necessary language of his discipline. On the other hand, Smalley was discoursing in terms of what the laws of chemistry would allow. He speaks, instead, of catalysts, reactants, and enzymes. Finally, there is no common measure in terms of method. Since Drexler is trained in the art of "conceptual exploration," his idea of adequacy require only the mechanical feasibility of molecular assemblers-the process of actual construction will come later.[23] Smalley insists on "actual implementation" and emphasize the need of what is feasible. The role of chemistry should be considered.

In his seminal work, *Engines of Creation (1986)*, Drexler introduced the idea of universal assemblers or nanomachines and was revived in his recent work published in 2013,[24] where he talks of 'atomically precise manufacturing,' as the key to rapid scientific progress capable of transforming the global economy and restoring the environment. However, Drexler was sidelined in mainstream nanotechnology. There is hardly any mention of assemblers or molecular machines in academic literature. But things may change with the 2016 Nobel Prize. Bern Feringa, Jean-Pierre Sauvage, and Sir J. Fraser Stoddart were awarded the Nobel Prize in Chemistry in 2016 for their design and synthesis of the "world's smallest machines;" the technology is already being used to create medical micro-robots and self-healing materials that can repair themselves without human intervention.[25] The pioneering work of this Nobel trio may be one of the first significant steps to the realization of Drexler's vision of self-assembling machines.

Ontological Status as a Discipline

Scholars have been debating regarding the status of nanotechnology, whether it is a distinct discipline. It is not even clear when the field was created. Some point to Richard Feynman[26] in 1959, others to Norio Taniguchi in 1974, and still others

[23] Bueno, 40.

[24] Eric Drexler, *Radical Abundance: How a Revolution in Nanotechnology will Change Civilization*. Public Affairs, 2013.

[25] Hannah Devlin, 'Nano-machines' win European trio chemistry Nobel prize, (2016).https://www.theguardian.com/science/2016/oct/05/nobel-prize-chemistry-2016-jean-pierre-sauvage-jean-pierre-sauvage-bernard-feringa-nano-machines.

[26] Feynman in his speech "There's Plenty of Room at the Bottom" made some allusion to biological nanomachines. This led Laszlo to conclude that the feasibility of miniaturization at the atomic level as conceived by Feynman was inspired by Watson's and Crick's discovery of the DNA double helix in 1953, arguing that if the size of the genome could contain such amount of information, then it is also possible for scientists and engineers to emulate this natural feat. See Laszlo's *Is There Life After Partington?,* Accessed at http://www. hyle.org/journal/issues/15-1/larrere.htm.

to Drexler in 1986. At a much earlier, James Clerk Maxwell in 1871, conceived of "extremely tiny "demons" that could redirect atoms one at a time" and M.I.T. professor Arthur Robert von Hippel was interested in molecular design as early as the 1930s; he coined the term "molecular engineering" in the 1960s.[27] So they too should qualify as founders. Surprisingly, as quoted by Allhoff, the physicist Richard A.L. Jones had somebody else in mind.

Perhaps a better candidate to be considered nanotechnology's father figure is President Clinton, whose support of the USA's National Nanotechnology Initiative converted overnight many industrious physicists, chemists, and materials scientists into nanotechnologists. In this cynical (though popular) view, the idea of nanotechnology did not emerge naturally from its parent disciplines, but was imposed on the scientific community from outside.[28]

Blurring boundaries: Nature- Artefact Distinction in Nanotechnology

At the outset, it would seem that nature is opposed to nanotechnology because technology is man-made and what is humanly engineered is artificial. Some researchers claim that nanotechnology has blurred the boundaries between nature and artefact. This implies that the artificial field is being grafted into the natural field resulting into hybrid technological products that render the distinction impossible. Let us further examine the concept of nature vis-à-vis artefact to determine how they relate to each other. Defined negatively, nature is that which is not produced by human action. Artefacts, on the other hand, are man-made. Gutchet advances two contrasting theories regarding the relationship between nature and artefact. The first theory stipulates that nanotechnology has 'artificialized nature' and would eventually erase the concept of nature. The researcher presupposes that this view corresponds to a vision of modernity, better yet of a transhumanist ideal. The second theory asserts that 'artefacts are naturalized' which means that the realm of nature is enlarged due to artefacts becoming less and less distinguishable from nature. Nanotechnology adopts the design strategies common in nature and assumingly the technological products will bear no difference from what is natural. A case in point would be genetically modified foods. Consumers will not be able to track or monitor which goods in the market are natural and which are modified. Given the fluid boundary of nature and artefact in nanotechnology, Schiemann posits the distinction between the two: "an

[27] Ibid.

[28] Allhoff conjectures that if Clinton can claim for himself the title "Father of Nanotechnology," it would not be a surprise why some scientists and engineers regard nanotechnology as merely a political construct or a marketing buzzword., with the goal of reviving the interest in the basic sciences that appear to be losing ground in the United States. See Allhoff, et al, *Nanoethics*, 31.

object is natural if it is impossible with all scientific methods available at a given time to detect that it was produced by human action; alternatively, an object is to be defined as artificial if it can be scientifically demonstrated that it was produced by human action."[29] However, he made it clear that mere intervention of human action does not constitute artificiality. This human influence on natural substances may be weak, as in the case of creating the appropriate conditions for initializing the synthetic processes involving molecules, or strong, as demonstrated by Eigler when he successfully moved 35 xenon atoms to produce the IBM logo.

In classical metaphysics, the distinction between nature and artefact presupposes the conceptual divide between being and becoming, structure and operation. Aristotle used the word nature to designate the shape and form which accord with the things account.[30] He also ascribed the term nature to the primary underlying matter of things which have in them a source of their movements and changes.[31] Nature is supposed to be static and stable whereas artefact is dynamic and unstable. But is the distinction still relevant? Gutchet avers that nature and artefact are two abstractions from the same reality. As such, the distinction between nature (structure) and artefact (operation) is not useful for nanoscientists. When they talk about nature, they are more concerned with what it does (operation) and not what it is (structure). We have to take note that there is already a shift in the supposition of the term nature from what we have previously established- as that which is not a human product. The meaning of nature takes a different connotation when it is understood as essence. *Oxford Dictionary* defines it as the basic or inherent features of a thing, especially when seen as a characteristic of it. Nature is seen in the light of its function or properties. For scientists and engineers, it is better understood in terms of its operations and processes, instead of perceiving it as structure.

Uncertainty and risks in nanotechnology

All complex technologies are characterized by uncertainty. It is a multi-faceted concept which can be reduced to a mere absence of knowledge. Sollie argues that: 1) uncertainty can prevail even in situations where a lot of information is available; 2) new information does not necessarily increase certainty, but might also

[29] Gregor Schiemann, "Nanotechnology and Nature: On the two Criteria for Understanding Their Relationship" in *Nanotechnology: Challenges and Implications for Philosophy, Ethics and Society*, ed. Joachim Schummer and David Baird, Singapore: World Scientific Publishing Co. Pte, Ltd., 2006, 81.

[30] William Charlton, trans. *Aristotle's Physics Books I and II*, (NY: Oxford University Press, 1992), 25.

[31] Ibid.

augment uncertainty by revealing the presence of uncertainties that were previously unknown or understated, and; 3) there might be situations of uncertainty that are indeterminable and which for the reason of the nature of that situation cannot be reduced by acquiring knowledge (for example, the behavior of other agents). There is uncertainty regarding the long term effects of nanoparticles in the environment. Some studies suggest technology assessment and life cycle analysis to address the sustainability issue, environmental, health and security concerns.[32]

On the other hand, risk refers to situations, in which probabilities can be assigned to known possible future states of the world while uncertainty has to do with situations in which probabilities cannot be attributed to future states, which are often indeterminate themselves. In the context of environmental protection, the World Commission on the Ethics of Scientific Knowledge and Technology (COMEST) equates risk with the possibility, with a certain degree of probability, of damage to health environment and goods, in combination with nature and magnitude of the damage. The study made by the International Risk Governance Council (2006) and the Scientific Committee on Newly Identified Health Risks (2005) suggest that there exists knowledge gaps regarding the nature of nanoparticles and emphasizes the need for an international framework with which to address risk at the global level. The further miniaturization of devices which may be implanted or worn as accessory will pose a threat to our security.

The nature of nanotechnology as a fledgling discipline and the issues that were presented in this paper will pose some opportunities and challenges to education and research, particularly in science and engineering.

Science and Education Implications

Nanotechnology is perceived as an interdisciplinary field. It lies at the intersection of physics, chemistry, engineering, and biology. The convergence of these disciplines is poised to bring an enormous impact in the various areas of human endeavor. To realize these possibilities, a commensurate response in the educational system is required. Current educational systems should address the need for a more collaborative approach. One of the challenges for education is to educate and train minds who will be the next generation of workers in multidisciplinary

[32] See Nanotechnology and Life Cycle Assessment: A Systems Approach to Nanotechnology and the Environment by the Woodrow Wilson International Center for Scholars (March 2007) http://www. nanotechproject. org, and Hischier, R. Int J Life Cycle Assess (2014) 19: 941. https://doi.org/10.1007/s11367-013-0698-6.

perspectives. In an interview[33] with Dr. Robert Chang, the director of the National Center for Learning and Teaching (NCLT) in Nanoscale Science and Engineering, noted that among the biggest challenges to nanotechnology-related education in the pre-college level are the need for better science and math training for teachers early in their careers and greater access to continuous high-quality professional development. At the higher education levels, the foremost challenge is to break down the barriers among traditional disciplines to offer students a more integrated view of the world. Eroding the barriers can be achieved through cross-disciplinary (physics, biology, chemistry, mathematics) pedagogical approach so that students will be able to observe and appreciate the interconnections among the sciences. The new interdisciplinary approach would likewise require retraining of teachers in order to improve learning and to impart results to their students. Along these lines, nano teaching resources designed to aid teachers with nanoscience and technology curriculum are made available at NanoEd Research Portal. This site is sponsored by the National Center for Learning and Teaching (NCLT)[34] in Nanoscale Science and Engineering.

According to Schank et al., there are two conceptual challenges in nanotechnology education: "a) nanoscale entities are generally difficult to both see and visualize, and b) different rules predominate at the nanoscale."[35] As to the former, the nanoscale is a concept that is difficult to grasp by students as compared to the stand units of measurement that they are accustomed to. Teachers have to be more creative by developing enhanced instructional tools and strategies such as visualization, modelling, simulation, and similar computer-based platforms. As to the latter, there is a need for teachers to be familiar with the laws of quantum physics. At the nanoscale, the magnetic, optical, mechanical, and electrical properties of things are changed. Students may find this difficult to comprehend and counterintuitive. Again, the teacher's creativity should be inexhaustible.

Other than the challenges of redefining the curriculum, teacher training and development of teaching materials, realigning strategies in teaching to meet the interdisciplinary requirement, and integrating societal and ethical considerations

[33] The except of the interview may be accessed at http://www.nano.gov/html/edu/interviews/20070709_Robert_Chang_interview.html.

[34] NCLT is the first national center for learning and teaching of nanoscale science and engineering education in the United States. It was created in 2004, through a National Science Foundation award of $15 million for five years. Its mission is to develop the next generation of leaders in nanoscale science and engineering teaching and learning. Ibid.

[35] P. Schank, J. Krajcik, and M. Yanker, " Nanotechnology as a Catalyst for Educational Reform" in Nanoethics eds. Fritz Allhoff, Patrick Lin, James Moor and John Weckert (New Jersey: John Wiley and Sons ltd., 2007). 287.

in the context of responsible use of nanotechnology should be given importance in nanotechnology education. The key to meet the challenge of a nanotechnology-ready workforce in the coming years is clearly through systematic and well-responsive educational reforms. The gap between the academe and the industry must be bridged.

Conclusion

"No Walls, No Ceilings, No Floors" is the title of the song popularized by Barbara Mandrell in the late '70s and early '80s. The title as employed in this article depicts the melting of boundaries, unforeseen horizons, and the lack of a stable foundation in nanotechnology. These conditions pose some challenges and opportunities to education and research particularly in science, engineering, and the humanities.

As we have shown in the previous discussions, nanotechnology will introduce shifts and transitions particularly in the field of science and engineering education. Firstly, nanotechnology will create a shift from the disciplinary model to an interdisciplinary approach. It will blur the boundaries between the basic sciences and engineering. The interdisciplinary nature of nanotechnology will require better collaboration among scientists and engineers across specializations. Citing Neurath et al., Paul DeHart Hurd writes, "There is a little recognition that in recent years, the boundaries between the various natural sciences have become more and more blurred and major concepts more unified."[36] This calls for a unified approach to learning and thematic instruction of science concepts and practices.

As a new and emerging technology, nanotechnology's potential is limitless; its horizons boundless. The rapid pace at which nanotechnology is moving requires the same kind of exponential growth in ethics research in nanotechnology. While it is filled with promises, it is at the same time laden with ethical issues such as complexity, risk, and uncertainty. This strengthens the need for integrating in the curriculum the teaching of the ethical and societal implications of nanotechnology.

Understanding the societal and ethical issues in nanotechnology will help the students frame their perspective as future professionals. Students will have a more holistic understanding of this emerging field. Debating controversial issues in nanotechnology will enrich their learning experiences. It will provide them an

[36] Paul DeHart Hurd, "Why Must We Transform Science Education," Educational Leadership, October, 1991, 33. https://pdfs.semanticscholar.org.

opportunity to develop their critical thinking skills that will make them engaged and proactive learners.

Nanotechnology involves the interface between complex systems and opens up the possibility of extending the notion of a multidisciplinary approach to nanotechnology by including the Humanities in the equation. Here lies the opportunity of bridging the traditional boundaries between *Naturwissenschaften* and *Geisteswissenschaften*. What remains evident is that the realm of nature is not at odds with the realm of the human spirit as the human lived experience is not an isolated but a collective enterprise. Science, Technology, and Society (STS) studies and professional ethics courses that involve nanotechnology may be enriched by new and emerging science and technology (NEST)-Ethics. Courses in Ethics taught at the tertiary level will gain more relevance with the introduction of controversial issues in emerging technologies such as nanotechnology. Ethicists and educators with the technical expertise from among the faculty can collaborate and help students build a meaningful understanding of nanotechnology.

Finally, nanotechnology brings together discourses from various interest groups – scientists, philosophers, policy makers, business, media and the social scientists. An examination of the foundational issues in nanotechnology through a philosophical lens is an indication of the privileged and prodigious role of philosophers and ethicists. Philosophy remains relevant in the current nanotechnology debates. PS

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