A Multidisciplinary Approach in STEM Education

Alden Dochshanov[1], Michela Tramonti[2]

Abstract

Following the idea that "at the nano level atoms do not belong to any field of science", the work discusses the concept of nanotechnologies and applied mathematics by treating them as the nowadays multidisciplinary convergence points and potential ideological fulcra for the educational approaches of the nearest future. In this context, authors analyze recent results (including their own) obtained in the fields of nanotechnology, biomedical engineering and mathematical education, to demonstrate the idea of synergetic efficiency and deeper understanding provided by such a multidisciplinary approach.
By introducing the results obtained in our recent research, we outline the diversity of the concepts, ideas, methods and problems to be dealt with during such a work, and how the final outcome can bring out not only in terms of the scientific development itself, but to be used as an immediate reference point for the teacher of today. In particular, we show that the introduction of the multidisciplinary point of STEM skills development turns the teaching and learning process into a problem-oriented creativity reasoning. The latter, in turn, eliminates the interdisciplinary constraints and paves a way to the understanding of multidisciplinary nature of problem solving approach.
Authors claim, to consider the enormous acceleration of technological development that we are witnessing, such a feedback, which connects the ultimate concepts of the modern science with the professional vision of a teacher, who in this case represents a crucial figure in the link "science-education-pupil", may be considered as a requisite by default.

Keywords: STEM education, multidisciplinary approach, Nanotechnology.

1. Introduction

The rapid technological development, exponential growth of the scientific information, diversity of the modern science are all the components that involuntarily may contribute to the phenomena known as "The Tower of Babel syndrome" [1]. When the level of professional specialization becomes overgrown with the immense amounts of data and specific terminology, it risks to entail such a level of interdisciplinary isolation, that does not permit the person, immersed into the certain research, to assess its relation even to the adjacent areas, to see the "forest as a whole", instead of continuous roaming in it.
To add, the idea that the research should become more interdisciplinary has become commonplace. And the question of whether a given knowledge practice is too disciplinary, or interdisciplinary, or not disciplinary enough has become an issue for governments, research policy makers and funding agencies as well [2].
Furthermore, it is universally recognized, that namely at the interface of different sciences the most prominent discoveries take place [3]. In addition, despite of immense load of experimental and theoretical machinery carried by every discipline individually, there is just a handful of simple, general ideas that forms a common spring, which, once mastered, opens the door to an enormous amount of front-line research [4]. Author claims, that we need an armature, a framework on which to organize the information flow we drowning in.
Thus, in the article, on the examples taken from authors experience and interest, namely nanoscience, biomedical engineering and mathematics, we show that the introduction of the multidisciplinary point of STEM skills development [5] turns the teaching and learning process into a problem-oriented creativity reasoning. The latter, in turn, eliminates the interdisciplinary constraints and paves a way to the understanding of multidisciplinary nature of problem solving approach.

[1] University of Rome La Sapienza, Italy
[2] Institute of Mathematics and Informatics - Bulgarian Academy of Science.

2. A multidisciplinary approach: some examples

2.1 Nanotechnologies and life science

The natural course of scientific development has introduced already fruitful and still promising concept of nanotechnologies [6], which, by the apt remark of Chad Mirkin [7]: "At the nano level atoms do not belong to any field of science", - invites us to unlock our minds and transform our attitudes, as we continue to live the adventure of nano science and technology [8]. Below, we try to demonstrate on a concrete example, why nanoscience may stimulate such a fusion.
In brief, the works [9, 10], [11] describe an application of nano-engineered plasmonic structure to the red-blood cell membrane surface analysis. The relevant point is that the study, fundamentally, was enabled by cooperative application of material science [12], plasmonics [13] and engineering [14]. In particular, the phenomena, that permits to recover the spectral contribution of the RBC membrane (~10nm thick, ~1000 thinner than RBC diameter), originates in nanoscale [15]. Material science, from its side, becomes a tool to create a nano-ordered structures in lab conditions [12], and to avoid appealing to much more sophisticated techniques as nanolithography for example. And, finally, the experimental tool [14], as a feat of modern engineering, permits to obtain the results would have been thought of as even unimaginable before.
Similar organization of work, with a free flow of ideas and cooperation between different majors has already become a daily routine in the leading labs throughout the world of academic and industrial research. The last is largely due to the nanoscale itself that promotes the advanced studies based on multidisciplinary vision. We strongly believe, that even partial adoption of this spirit and ideology could bring closer the curricula of secondary and higher education with the forefront research.

2.2 Biomedical engineering

Biomedical engineering represents a universal platform where every problem to be solved stimulates a harmonious combination between physiology, electronics, signals and images processing, mathematical modelling and simulation. A cursory look at the contents even of the introductory textbook on biomedical engineering [16] is enough to see the variety of the subjects covered. From the other side, it is not surprising that biomedical engineering is a real challenge for the definition of technological and medical aspects of the courses, provided that the ever increasing technological growth eliminates any intention to cover all the related subjects completely [17].
Nevertheless, biomedical engineering community has already developed extremely powerful instruments, from both methodological and scientific point of view, that would help to shift paradigms in educational approaches, accelerating essentially the interest and involvement of the students. In particular, the use of electronic circuits in simulating physiological processes [18], [19], as the modern approach to teaching physiology to postgraduate medical students showed an increasing interest for this type of teaching. Authors [19] underline, that the development of equivalent circuits, indeed has many advantages. Among the most important ones is that following the method, the student is encouraged to develop analogous (semi)quantitative thinking and therefore to stimulate his/her creativity. The last fact is of extreme importance, especially for medical students, who are joining more quantitative way of thinking, and receiving the fundamental understanding that physiology can be perceived not just as the set of qualitative facts; but can be treated as the subject of quantitative inter-relations and can be directly modeled and, thus, understood at much more deeper level.
In addition, be aware of this intimate correlation between such a different physical objects (electronic circuits and physiological systems), allows student to attain a certain level of mental flexibility to move more fluently between different kinds of systems provided the formal analogies are well established and justified [20]. Moreover, once the analogy understood and acquired, such a kind of methodological approaches opens the doors to the mastery of other adjacent disciplines (electronics in our case). And once a student decides to master it, a huge head start is already at his/her disposal, cause an essential part of the content had already been covered in the frame of the concrete context, and a student has a clear understanding how, for example, the general output of an electronic system is related to the nominal value of a certain component (e.g. resistor, capacitor, etc.).
Thus, as one can see from the above example, the educational ideas of biomedical engineering could be use if the development of multidisciplinary vision is desired.

2.3 Engineering math

Unifying and all-pervading nature of mathematics, most regrettably, often remains unclaimed. Meanwhile depending on the manner of a pitch chosen, powerful unifying principles of engineering mathematics [21], for example, could be easily deliverable. The eminently suitable example to illustrate the idea is the electromechanical analogy, which lies in the same mathematical form for an electric RLC-circuit and a mass-spring system. Being strictly quantitative and of extreme practical importance, the model helps to treat the mathematics as concise but extremely capacious mediator that binds elegantly different physical entities. Therefore, the direct relation of a mathematical concept and physical entity combined with the unifying ideas presented within the math edifice, to our mind, may serve as another strong instrument to use towards multidisciplinarity acquisition.

3. Conclusion

Given the rapid growth and accumulation of the scientific information, a student, to succeed in the future professional career, needs not only the solid background in fundamental disciplines, but an essential mental flexibility in terms of the development of a combined inductive-deductive vision together with a freedom of inter-, multidisciplinary receptivity. To this end, the ideas, methodological approaches, diversity and universality of the subjects involved that lie behind the concepts of nanotechnologies, biomedical engineering and mathematical education may be adapted as a ready-to-use model tool, "ideological fulcra", for the educational curricula of today.
From the other side, it is obvious, that preserving the nomination of a highly-qualified professional today is synonymous to the permanent self-education as never before. Therefore, the capacity of seeing no interdisciplinary borders, thus optimizing the learning effort distribution, understanding a close relation and formal analogy of different physical phenomena multiplied by the strongest unifying and all-pervading elegance of mathematics are those "shoulders of giants" [22] that would help next generation to see further.

References

[1] D. Haight and M. Cannavo, "The Tower of Babel syndrome," Administrative radiology journal : AR, vol. 15, pp. 36-37, 1996.
[2] A. Barry and G. Born, Interdisciplinarity: Reconfigurations of the Social and Natural Sciences: Taylor & Francis, 2013.
[3] J. Moran, Interdisciplinarity: Taylor & Francis, 2010.
[4] P. Nelson, Biological Physics: Energy, Information, Life: W. H. Freeman, 2003.
[5] M. López-Huertas, "Reflexions on multidimensional knowledge: Its influence on the foundation of knowledge organization," Arqueologia Mexicana, vol. 40, pp. 400-407, 2013.
[6] D. Newberry and J. Uldrich, The Next Big Thing Is Really Small: How nanotechnology will change the future of your business: Random House, 2010.
[7] http://www.chemistry.northwestern.edu/people/core-faculty/profiles/chad-mirkin.html.
[8] S. F, S. Szunerits, A. Vasilescu, and W. Knoll, "Nanoscale Architectures for Smart Bio-Interfaces: Advances and Challenges," 2011.
[9] G. Zito, G. Rusciano, G. Pesce, A. M. Dochshanov, A. Malafronte, G. Ausanio, et al., "Plasmon-enhanced Raman spectroscopy: Towards hyperuniform ultrasensitive enhancement through hyperuniform disorder," in 2014 3rd Mediterranean Photonics Conference, MePhoCo 2014, 2014.
[10] G. Zito, G. Rusciano, G. Pesce, A. M. Dochshanov, and A. Sasso, "Surface-enhanced Raman imaging of cell membrane by a highly homogeneous and isotropic silver nanostructure," Nanoscale, vol. 7, pp. 8593-8606, 2015.
[11] G. Zito, A. Malafronte, A. M. Dochshanov, G. Rusciano, F. Auriemma, G. Pesce, et al., "Surface-enhanced Raman imaging of red blood cell membrane with highly uniform active substrates obtained using block copolymers self-assembly," in Proceedings of SPIE - The International Society for Optical Engineering, 2013.
[12] W. J. Cho, Y. Kim, and J. K. Kim, "Ultrahigh-density array of silver nanoclusters for SERS substrate with high sensitivity and excellent reproducibility," ACS Nano, vol. 6, pp. 249-255, 2012.
[13] E. C. Le Ru and P. G. Etchegoin, "Single-molecule surface-enhanced raman spectroscopy," in Annual Review of Physical Chemistry vol. 63, ed, 2012, pp. 65-87.
[14] http://www.witec.de/products/alpha300-series/alpha300-r-confocal-raman-imaging/.
[15] M. G. Albrecht and J. A. Creighton, "Anomalously Intense Raman Spectra of Pyridine at a Silver Electrode," Journal of the American Chemical Society, vol. 99, pp. 5215-5217, 1977.
[16] J. Enderle, J. Bronzino, and S. M. Blanchard, Introduction to Biomedical Engineering: Elsevier Science, 2005.

[17] M. Nadi, "Biomedical engineering education: Problems related to multidisciplinarity," in Proceedings - Frontiers in Education Conference, FIE, 1992, pp. 118-121.
[18] D. G. Tsalikakis, D. I. Fotiadis, and D. Sideris, "Simulation of cardiovascular diseases using electronic circuits," in Computers in Cardiology, 2003, pp. 445-448.
[19] M. Rupnik, F. Runovc, and M. Kordaš, "The use of equivalent electronic circuits in simulating physiological processes," IEEE Transactions on Education, vol. 44, pp. 384-389, 2001.
[20] J. Keener and J. Sneyd, Mathematical Physiology: II: Systems Physiology: Springer New York, 2009.
[21] E. Kreyszig, Advanced Engineering Mathematics: Wiley, 1999.
[22] I. Newton and H. W. Turnbull, The correspondence of Isaac Newton: Published for the Royal Society at the University Press, 1959.