Annals of Systems Biology

Durjoy Majumder[1,2*], Dibyendu Kumar Ray[1,3], Ishita Chatterjee[1,4], Ranjan Kumar Gupta[1,5], Abhik Mukherjee[1,6], Tarun Kanti Naskar[1,7], Probir Kumar Dhar[1,8] and Asesh Banerjee[1,9]

[1]Society for Systems Biology and Translational Research, Block-C, Bangur Avenue, Kolkata, India
[2]Department of Physiology, West Bengal State University, Barasat, 24 Pgs (N), Kolkata, India
[3]Department of Neurosurgery, Bangur Institute of Neurosciences, Sambhunath Pandit Street, Kolkata, India
[4]Department of Applied Psychology, University of Calcutta, APC Road, Kolkata, India
[5]Department of Management, West Bengal State University, Barasat, 24 Pgs (N), Kolkata, India
[6]Department of Computer Science and Technology, Indian Institute Engineering Science and Technology, Shibpur, Howrah, India
[7]Department of Mechanical Engineering, Jadavpur University, Raja SC Mallick Road, Kolkata, India
[8]Department of Electronics and Communication Engineering, Bengal College of Engineering and Technology, Durgapur, India
[9]Department of Laboratory Medicine, All Asia Medical Institute, Garcha First Lane, Kolkata, India

Dates: **Received:** 01 July, 2016; **Accepted:** 04 August, 2016; **Published:** 06 August, 2016

***Corresponding author:** Durjoy Majumder, Department of Physiology, West Bengal State University, Berunanpukuria, Malikapur, Barasat, 24 Pgs(N), Kolkata 700 126, India, E-mail: durjoy@rocketmail.com

www.peertechz.com

Keywords: Systems biology; Systems medicine; Higher education in India; Health care; Cognition in education

Review Article

Importance and Implementation Strategies of Systems Medicine Education in India

Abstract

Though the inevitable outcome of Systems Biology (SB) may be directed to seek answers to the medical problems; however, due to its expanding horizon and flexibility, different academic institutions across the globe focus on different aspects of SB in their educational curriculum. Hence, some European educationists propose for streamlining of different course curriculum. Here such issues are discussed with respect to their translation towards medicine and health care system i.e., Systems Medicine (SM) under the perspectives of developing countries. Conventional molecule centric high-throughput technology driven practices of SB that are being carried out in Western world may not fit under the perspective of developing countries due to associated high cost. Streamlining approach for SB course curriculum would shift the multi-/interdisciplinary (MDID) framework of SB towards more rigidity and narrow down the scope for the development of the subject in developing countries. Since independence of India, policy was adopted so that field dependent (FD) cognition has got priority. Present educational policy makers are trained with that direction; hence, they remain ignorant about the importance of other facets of education. Still there is some unawareness regarding the long-term effect about the implemented policy for country's development. Practice of SM is the need of time to address the regional and local problems. Development of domain knowledge and analytical methods should be prioritized for developing countries. This would invariably take an initiative towards further development of computational methods, information and web technology and automation; thereby its vastness and expanding horizons would be appreciated. Such activities may also shift the existing health care paradigm in near future. Learning process and education on SM through research could be the ideal path for the development of the subject. This, in turn, may blur the demarcating lines across and between the far disciplines and make a paradigm shift in the educational system across the globe.

Introduction

Systems Biology (SB) is now considered as one of the most emerging field of science and has become the part of mainstream biology across the globe. It is very difficult to define this subject. Though numerous definitions are put by the experts; however, so far there is no consensus definition for the subject, rather each researcher in the field differs from other. Nevertheless, the experts in the field welcomed newer definitions of the subject so that newer ideas can penetrate into this area. Humbly, we would like to define SB as a quantitative approach or attempt to decipher the complex inter-relationships between the biological components across the scales of an organism's microcosmos to reveal the mechanism of sustainability of the life of that organism within this mesocosmos. Interested readers may consult the papers Kirschner, 2005 and Breitling, 2010 [1-2]. Undoubtedly, through SB, the complex biological processes can be revealed in a better manner; however, in different occasions, one of its applicative area i.e., Systems Medicine (SM), is addressed frequently by different experts of the field and suggested that health care system would be most benefited through it [3-13]. Like SB, numerous definitions are also available for SM, interested readers may consult the recent article written by Marc Kirschner, 2016. To us, SM is an implementation of SB approach to identify the key component(s) or mechanism(s) of the physiological system in an understanding of the pathophysiological state(s) transition, so that minimal procedure(s) can be adopted to maintain the sustainability of one's life as long as possible with the ethical applications of all existing scientific knowledge.

This area would specially be important for the multifactorial non-communicable diseases (NCD), as NCD diseases are considered to be the major health burden. As per 2008 data, 36 million deaths each year are caused by NCD, whereas 6.7 million people died of infectious diseases. This has been reflected in the 2008 Action Plan of World Health Organization. Contrary to popular opinion, available data demonstrate that 80% of NCD deaths occur in low- and middle-income countries [14-16]. Possibly this may be the reason for the development of e:Med research and funding concept by Federal Ministry of Education and Research, or recent announcement of US$ 215-million N-of-1 project by US President Barack Obama [17,18].

The member states of SAARC (South Asian Association for Regional Cooperation) countries are Afganistan, Bangladesh, Bhutan, India, Nepal, the Maldives, Pakistan and Sri Lanka. SAARC

comprises 3% of world area, 21% of world's population and 9.12% of global economy as of 2015 [19]. As per World Bank income classification, all the member states of SAARC countries, except Maldives are considered within the low-income countries. More than 80% of the world population lives in low-income countries. Among the SAARC countries, India has a large population (nearly 1.3 billion people that accounts for 17% of the world's population) and holds the third economy ranks in terms of purchasing power (its gross domestic product based purchasing-power-parity, PPP valuation of country GDP is about $79996 billion) in world [20]. It also bears a worldwide reputated $100-billion information technology industry and 1013 million US$ (in 2012) pharmaceutical industry and have a noticeable success in astronomy, space science and biology. As per FICCI Higher Education Summit 2014 report, "India is well-positioned to cater to the changing requirements of the labor market in domestic and international markets due to favorable demographics and large output of higher education graduates" [21]. India produced 90.5% of total biomedical publications generated by the SAARC countries [22]. All these may be the reasons to expect that India has the potentiality to become the "south Asia's super-power" in science. As per 2013 report, 5% of global shares of clinical trials is India's share estimation [23,24]. Moreover, 80% of donor funded antiretroviral medicines in Africa come from Indian generic manufacturers [25]. The World share of biomedical research output is gradually growing from India along with China and Brazil [26]. Several problems in the health care system are also common for different developing countries across the globe [27]. Hence, development of science in Indian context could be an important issue as India could be the representative for the growth and development of science among different developing countries across the globe [28].

Total number of students and teachers in higher education in India are 33.3 million (23.6%) and 1,418,389 respectively with a pupil: teacher ratio of 24:1 in Indian universities. Among the total students enrolled 0.34% are Ph.D. students [29]. Major enrolment of students in undergraduates are in Arts (34%) followed by Engineering & Technology (19%), Commerce (14.5%) and Science (12%). There is no separate data for number of enrolled students for different science disciplines. As per NSF 2010 report, India's priorities for research (on the basis of journal publication) in different disciplines are 28% in biomedical research, 67.7% in Physics and Engineering and rest in Social and Agricultural Sciences [30]. The total number of foreign students enrolled in higher education is 31,632. Highest share of students come from the neighboring countries, of which Nepal is 17%, followed by Bhutan and Iran (7%), Malaysia and Afghanistan (5%) [31].

Though several facets of science has an enormous growth in India as reflected in terms of purchasing power, but it has some serious major pitfalls even among the SAARC countries [32]. For example, it holds the 7th position in terms of life expectancy (presently the value is 67 which lag after Bhutan, for Bhutan the value is 68) and only 69% of population enrol for senior secondary education (which is less than Bangladesh, for Bangladesh the value is 78%) [33]. These data signify that it has some major drawback to become the "south Asia's super-power" and hints to readdress the policy for the biomedical education and health care systems to meet the challenge [34].

Venture of SB in India and other SAARC countries

As per recommendation of the Fourth Meeting of the Working Group on Biotechnology (Colombo, 27 April 2011), SAARC, the National State-of-the-Art Reports on Biotechnology was uploaded by six Member States (except Afghanistan and Maldives) to the SAARC websites. In the uploaded report of none of the countries, there is no mention of SB activity. Web search using Google does not generate any hit on SB activity in each of the member countries of SAARC except for India. For Indian activities on SB, website of Indo US Conference and Workshop on Synthetic and Systems Biology, 9-12 Nov, 2014, Jawaharlal Nehru University (JNU), New Delhi reveals some information on SB related activity in India.

Few Indian research groups have started work in different areas of SB in India. Though Indo US Conference and Workshop on Synthetic and Systems Biology, 9-12 Nov, 2014, JNU, New Delhi reported that National Centre for Biological Sciences (NCBS) has initiated SB activity as evident by wining of prize in IGEM competition at MIT [35]. However, in the same year, another group from Bengal Engineering & Science University, Shibpur (BESUS) (presently Indian Institute of Engineering Science & Technology) published two papers in the Journal of Biological Systems [36,37]. Other research groups from India namely at the University of Kerala, Bose Institute, Jawaharlal Nehru University, Indian Institute of Integrative Biology are working on the interface of Bioinformatics, Systems and Synthetic Biology. They are actively working on cell cycle, cellular signaling network, inter-cellular communications and cooperative behavior of microbes.

Though the number SB research groups are growing in India; however SM is quite neglected in Indian context. About a decade ago, a research group from BESUS, the only SM research group from India, has suggested that developing countries would be most benefited with the practices of SM; however, unfortunately, SM has not got the deserving recognition in India. It is to be noted here that in recent time several suggestions were put forwarded by different research groups across the globe, for example, metronomic chemotherapy would be the ideal and effective alternative for the management of cancer or treatment of cancer for a dollar a day or drug repurposing or individualized Systems Medicine for cancer therapy - interestingly, all these were suggested a decade ago by the Indian research group while working on Cancer Systems Medicine [11,12,38-44].

The inherent reason may be due to its multidisciplinary and/or interdisciplinary (MDID) nature of SB; and the different limiting factors and its overcoming avenues for the growth of the subject is discussed in recent time [34]. In fact in the fifth Annual meeting of Global Research Council held from 25-27 May 2016 in India advocates for promoting interdisciplinary research [45]. Possibly, the growth of the subject is also an issue in the western world as well and development of newer strategies in the educational sector has gained importance [46]. In India, Jawaharlal Nehru University is conducting an M. Tech. course in Computational and Systems Biology under the umbrella of Computational & Integrative Sciences and Punjab University is conducting M.Sc. course on Bioinformatics & Systems Biology under the umbrella of biology program. Rest of the

teaching programs are being carried out as the part of Bioinformatics, Computational Biology and different biology educational programs in a few Indian universities. For example, University of Hyderabad is conducting course on Systems Biology as part of Biotechnology & Bioinformatics, in Bengal Engineering & Science University (presently, Indian Institute of Engineering Science & Technology) had conducted course on Systems Biology from 2006 to 2009 as part of Bioinformatics curriculum under the umbrella of Information Technology and in West Bengal State University, SB had been taught from 2009 to 2016 as part of Physiology curriculum under the umbrella of Science faculty. There is no dedicated department in country for SB [35]. But such conducted programs as well as several lacunae in higher education in general are the limiting factors for its proper growth. In the 12th Five Year Plan, Indian Planning Commission placed a report on "Synthetic and Systems Biology Resource Network (SSBRN)". However, in that 44 pages report, there are only 3 lines mentioned on Systems Medicine and much emphasis is put on the Synthetic Biology that ultimately directed towards test tube based investigation. Although in that report, medical aspect is included with an emphasis on the communicable diseases but the management of persistent infection is ignored and/or not highlighted. As a result product based applications are overemphasized. It could not be irrelevant to mention here that many biomedical research advances are translated into medical improvements outside the realm of commercial product development [26,47,48]. Possibly in Indian scenario, Synthetic Biology research programs are easy to practice, as it is an extrapolation of in vitro biochemistry and mostly confined within lab environment [1,13]. The same sorts of policies are reflected in the 12th Five Year Plan (2012-17) that has been placed by the working group for Health research. In the 39 pages report, only the word 'Bioinformatics' is used a single time as a support system along with e-library and Biostatistics and there is no mention about SB or SM or Computational Biology. Interestingly, much emphasis is put to infectious diseases. In this connection the comment of Dr. Ala Alwan, Assistant Director-General, Noncommunicable Diseases (NCD) and Mental Health, WHO is important "Despite abundant evidence, some policy-makers still fail to regard NCDs as a global or national health priority. Incomplete understanding and persistent misconceptions continue to impede action. Although the majority of NCD-related deaths, particularly premature deaths, occur in low- and middle-income countries, a perception persists that NCDs afflict mainly the wealthy" [14,49].

Laboratory versus clinic

In Indian context, the major limitation is that in most of the Indian universities, biomedical science is considered and practiced as a part of biology curriculum. Though biology helps in shaping the biomedical science; however, core biology curriculum is far away from clinical and/or medical problems of the real world. As a result, it is confined as an exercise of theory and lab based practices. This keeps away the trained personnel from real world deployment of their knowledge. Recently Cvijovic et al. 2016 [46], proposed some structure for the Systems Biology education curriculum. But its translation towards Systems Medicine (SM) is questionable and may be inappropriate for serving the health care sector in the global context, especially for the developing and poor countries. The prime reason is that in the proposed curriculum structure, major emphasis is put on the test tube based science and/or its associated computational skill. There is no scope to be witnessed for clinical cases and its exposure. If there is any scope, the trained personnel with the proposed European SB education strategy have to depend on the secondary source. Data capturing and gathering of clinical information is different from lab-based environment, as in clinical environment most of the variables are beyond the control of the investigator. The main challenge of SM is to learn the synchronization and integration of data between lab and clinic. SB, especially SM do not have the objective interest of Physics or Chemistry, hence it requires a training and mind-set to capture and analyze the spatio-temporal variability in individual patients [1,11-13]. It is quite unfortunate that in Indian context, majority of the teaching faculties (of the biology programs) do not have any training regarding clinical scenario and all of their knowledge about human diseases are confined within either the secondary source of information, or animal or cell line based models. To cite an example, majority of the master's degree biology students can give right answers and explanation to the questions on stem cell, pluripotency, totipotecy, placenta, placental hormones, fetal circulation; but majority of them get confused and remain unanswerable to the question "What is the fate of placenta after child delivery?" There is a prevailing tendency to ignore the dynamical and qualitative behavior of human diseases in most of the biology programs. With the proposed European SB educational strategy if followed, the gap between knowledge and its translation would enhance.

Undoubtedly, training with the proposed European skill sets, personnel would be equipped for pharmaceutical and biotech industries, and possibly drug industry will shape its representation with new terminologies. As a result, the translational aspect would be inclined towards product development rather than biomedical concept development. This, in turn, hampers its development by making a wide gap between its true philosophical intentions and pursuing practices. This ultimately turns SB to another biotechnology discipline with a new nomenclature.

Issues relating to disciplinary training in Indian scenario

In Indian context, educational structures are rigid and under bureaucratic control, hence several forms of clerical assessments are imposed during faculty recruitment in higher education [50]. Till now there is almost no scope for getting jobs for personnel with SB skills. Majority of the cases such applicants are equated as bioinformatician or computational biologist or mathematical biologist [34]. Hence such streamlining effort would make it much more rigid. It is needless to mention here that in reducing time and cost of developing new drugs, systems approach is the utmost needed requirement for the reassessment of existing drugs. This seems to be impossible without witnessing the clinical problems. Though sensing technology is questionable regarding high-throughput science; however, India and other developing countries may not be able to pursue this aspect of SB and need to follow the Middle-out Rationalist Approach (MORA) [11,12,40,43]. In this connection it is to be noted here that high-throughput science "made us aware that there is a world outside our laboratories" [1].

SB or SM requires a MDID framework. To appreciate and understand the MDID framework a mature mind-set is needed. Possibly, an immature mind-set is not capable enough to adopt diversified philosophies and different inclinations associated with different disciplines. Philosophical understanding of one discipline plays a crucial positive role in appreciating and understanding of the philosophical inclinations of other disciplines. Within the scope of 3+2 educational structure, only specific skill sets can be taught [51]. Curriculum teaching even with an admixture of some specific topics from diversified fields at an early educational carrier ultimately tends to be a unidirectional discipline. Such initiative may be referred as "disciplinary baptism" [52]. If any predefined educational framework for a subject with MDID nature is practiced, then its MDID framework will be lost and turned it into another hybrid subject. So the European perspective for streamlining proposal on SB educational curriculum would be ironic [46].

Thus far, biomedical science is descriptive and different disease problems are judged symptomatically through clinical investigation [13]. It is the trend that symptomatic understanding is generally disregarded as non-quantitative by the lab based scientists, but recent advancements of artificial intelligence and operation research may help to shift such issues into quantitative perspectives. It is interesting to note that a lot of lab based quantitative understandings, even the static nature of data are now being explained with these analytical techniques. Therefore, different lab based subjects are heavily dependent on these analytical methods. For providing better health care benefit, much emphasis should be put to cost-effective medical interventions at the expense of priority interventions with an address of social determinants [53]. For improving the health of poor people, traditional treatment procedures can be the important way-outs [27]. However, methods of evidence based medicine may not be effective in proper assessment of traditional medicines that are being practiced across the globe, as majority of such practices are based on symptoms of individual patients. Thus the same dose or drug formulation may not or difficult to be applied on large populations. Through SM, qualitative assessment as judged by clinical symptoms can be transformed into quantitative statements through use of multi-scale modeling, inequations and fuzzy logic. In this manner, traditional medicine can get the proper scientific judgment. In addition, service sector of health care system would be improved. Unfortunately there is no mention of different clinic based practices in the proposed European educational perspective [11,12]. European suggestion of SB education has its focus on product-based development, which is a form of commercialization and commodity practice. It is influenced by the macroeconomic policies applied across the globe, whereas the issues of development of service sector in health care profession remain ignored. Hence streamlining approach may not be the right way to address the different health related issues in developing countries.

Uncoupling of teaching and research by focusing on mere teaching curriculum with the assignment of a new name is an old trend. Similarly, teaching curriculum related to different disciplines of hybrid nature such as Biochemistry or Biophysics has already been developed long time ago. This is a strategy to drag funding from establishment and a survival strategy for educational administrators in the changing paradigm of learning and development of knowledge [2].

Across the globe, faculties are recruited in higher education based on their previous training. In India, previous training means an acquired degree in a particular discipline and to ignore research training. So, disciplinary training has a narrow sense in India and the sense is implied only to the training that one has acquired through classroom based teaching curriculum. The most detrimental part of such practice is that it not only makes restriction to allow newer dimension to discipline, but also makes a continuation of outdated practices [21]. Suppose a person gets his bachelor's and master's degree in Chemistry, thereafter gets a Ph.D. degree in Medicinal Chemistry with a work in the field of QSAR, for example. In Indian higher education structure (as per UGC guideline one has to have a Master's degree in relevant subject), he never gets faculty job in the allied disciplinary department like Biochemistry or Pharmacy [54]. He can get his job only in the department of Chemistry. The "disciplinary baptism" has a narrow potentiality in Indian higher education.

Though numerous evidences become available, but biomedical sciences and health care system do not accept any newer therapy or protocol based on mathematical rationality and still remain dependent on the population based evidences. This is in contrast to the disciplinary culture of physical sciences. Therefore, major SB activities are confined within lab-based practices with model organisms or cell lines. It is needless to mention here that research findings for MDID nature generally published in newer journals and in majority of the cases, such journals have no impact factor. Generally, the established journals with high impact factor do not accept research findings until it gets an experimental or clinical validation. SM requires long-term clinical data to fulfill the criteria of journals with high impact factor [11,55]. Contrarily, funding agencies and ethical committees do not allow for clinical trials until a research group has a high impact factor journal publication. This is especially important in the Indian context. It is also an undeniable fact that in developing countries, there are enormous chances of misguidance and exploitation of poor patients during medical care. So a 'standard of care' is needed for implementation of newer therapy or protocol [56,57]. For validation, some patients' data are needed. For getting those data, development of standard patient care system is essential. And for development of such system, funding is essential. This makes a delay in appreciation and/or translation of newer findings of SM into treatment and clinical care. As a result, poor patients would suffer [53]. This is the major hindrance in the growth of the subject especially towards its implementation. Although, in 2011, European Medical Research Councils (EMRC) strongly recommended "The results of biomedical research should be rapidly and efficiently brought to the patient"; however the present scientific culture in the field of biomedicine makes a vicious cycle which is often criticized as "Assigning of well-defined skill sets with lab based practices is a ridiculous Marxist framework" [26,58]. Possibly this may be the reason that presently, majority of the clinical translations of SB are oriented towards high-throughput data collection followed by network analysis. Undoubtedly this area has diagnostic implications.

However, such works may remain confined within the static nature of data, dichotomy of states (disease versus normal) and SB is being projected as an extrapolation of the subject Bioinformatics [59].

Priority- teaching versus research

To determine the priority between research and teaching for an academician, a long time debate exists in higher education. Undoubtedly in uni-disciplinary field, research may produce a specialist with a narrow skill set [60]. However, an opinion on the contrary says that a regular researcher can do teaching much better than a non-researcher due to his constant exposure to the expanding and emerging trend in the subject [61]. The former proposition prevails in Indian education sector. Moreover, due to budgetary constraint, majority of the universities' departments are run with minimum number of faculty staffs [34,62]. As a result, majority of the Indian universities turn out to be the teaching universities. And, possibly these are the reasons as to why individuals with undergraduate teaching experiences (in substantive position i.e., position with some retirement benefit) get more preference than the individuals with substantial research experiences during recruitment for teaching positions in university. In India, most of the undergraduate teachings are conducted in affiliated colleges under respective universities. Although affiliating college system may be a major hurdle to maintain the global standard of higher education, but it constitutes a major part of Indian higher education [50,63]. However, for a subject with MDID framework, consideration of previous teaching experience may be insignificant, as there is no defined pre-requisite skill as for conventional disciplines.

Implementation strategy

We suggest that for SB, especially for SM, academic curriculum would be best suited after post-3+2 period. Additionally, learning on SB is possible only through research. Hence, development of new educational structure with a joint MD-MS program may be suitable. Georgetown University already started such MD-MS dual degree program in the field of SM [64]. Such program is needed to be designed with such a fashion that it would lead towards doctoral thesis. The eligibility should be of multidisciplinary nature in such a way that students from different faculty structures would be allowed. MD-MS program on SB/SM has a special relevance as it provides the trained personnel with a scholar-practitioner entity, which also has the relevance in global context. Presently, due to budgetary constraint in education sector, there is gross reduction in tenure-track faculty positions with the substantial growth of contractual faculty positions in different countries across the globe. Ironically in Indian context, tenure-track faculty position is synonymous with contractual position [63,65]. With respect to the vast population of India, there is an acute shortage of clinical staff and heath care professionals. 2015 National Health Profile report reveals that there is one doctor for every 11528 people and one nurse for every 483 people [66]. Therefore, such SM training programs would be helpful in serving a greater portion of the population. A 2004 report reveals that in the world one billion people do not have access to health care facilities [27].

Learning through research is best suited for the subjects with MDID framework. Even in conventional medical education 'Problem Based Learning' is effective in different countries outside India [67]. However, it is difficult in the Indian context as teaching and research are not integrated in majority of the universities and classroom-teaching activities are emphasized as academic activity [21,50,68]. In recent amendment of University Grant Commission (UGC, a regulatory body of Indian universities), classroom teaching workload is enhanced and the funniest thing is that hour workload for practical classes is equated as half compared to classroom teaching. This clearly signifies that much extra emphasis is given to information delivery, which is the major component of classroom teaching. However, this is really a major bottleneck in the development of majority of science disciplines in India [69]. Along with this, UGC took an initiative to make a list of journals in an assessment of research of a researcher [70]. This creates a further hindrance in the practice or venture into the emerging areas of the disciplines. It is globally acknowledged by the researchers involved in MDID framework that research communications of MDID nature is generally published in newer journals and most of them do not have impact factors. A considerable number of breakthrough researches have been published in several such newer journals. Moreover, assignment of higher priority to a select group of journals promotes a monopoly in publication business as no new journal or new publisher will come out in future due to a lack of viable market. There is little scope of learning through research or there is no scope of evaluation of students through their research performance and whatever exists, is either vaguely defined or confined within a very short span of time within the existing curriculum.

Witness to reality – education in Indian context

In Indian educational sector, many of us have witnessed several unique experiences. For example, a boy in school at 4th standard can easily handle to draw pictures through the paint program even in Linux operating system and he enjoys this. However, surprisingly, he failed to secure pass marks in his school examination with the syllabus covering on Paint. While finding the reason, it was found that examination system was based on pen and paper and there were some theoretical questions that he was unable to write answers correctly by making several spelling errors. While another boy who got more than 90% marks in the same examination, when provided with a computer and asked to draw a picture using Paint program became perplexed. And, on being asked the reason for his problem, the latter student expressed that he did not know how to switch ON the machine. Similar experiences are also shared in some recent articles, where another little boy got less marks compared to other children of his class due to writing of an answer by his own instead of regurgitating answers that is present in his book [71,72]. Such experiences in other forms are also frequently seen in higher education in science where importance on practical training is ignored [73]. Continuation of such problem is plausibly due to the educational policy makers' ignorance regarding science as reflected in the recent amendment by UGC where workload for practical class is considered as half to the class room teaching workload [69,74,75].

Since the independence there is no single Noble prize winning scientific or technological discovery from India; however, three Indian born scientists won Noble prize with their work done entirely

outside of India. In 2015-16, none of the Indian university could manage a rank within the top 200 universities of the world, although some national level research institutes hold rank within top 600 position [23,76]. These data may hint towards some serious lacunae in Indian higher educational policy. Due to unavailability of reliable data, there is only some fancy ideas prevail towards raising the levels of higher education which rather leads to ad-hocism and chaos [50]. Possibly class room teaching, with a mere focus on development of professionals with single theme is not the solution for improvement of educational standard. Focusing on a single theme like technology or medicine or management is the major hurdle to get away from the global requirement of MDID activities in higher education [77]. Hence, a streamlining approach in SB, especially in SM, may bring detrimental effect for India as well as for other prospective developing countries.

Experimental versus mathematical skill

There is an overwhelming idea in the educational sector that biology students cannot acquire mathematical skills or Mathematics and Physics trained persons cannot acquire biological experimentation skills. But some of us are having different experiences while conducting teaching courses on SB (as part of Bioinformatics and/or Biology courses) for a decade in two major universities in the eastern part of India. Students irrespective of their previous trainings are able to learn and adopt different skill sets - experimental, mathematical or computational; but they face difficulty when they are asked for any real world deployment on clinical or human disease problem. With all the available resources in experimental, computational or for information on a particular disease aspect, students are generally able to make the right algorithm and computational programs; yet they are unable to produce any realistic sense regarding the dynamical pattern of human diseases. For example, when they are asked for Eigen analysis, they make perfect calculation; but when they are asked to apply it for a particular disease case, they are perplexed. The inherent reason is non-exposure to clinical conditions. The same Eigen analysis may be handled in a different way for different human diseases. In either of the two universities, there is no medical faculty structure and hence, there is no scope to give exposure to the students regarding clinical aspects. Even the educational curriculum and administrative structure do not support to proceed towards fulfilling this purpose. Hence, skill-sets with mathematical or computational jugglery, which are generally equated with higher academic potentiality, may not be the only solution to get a real solve for human diseases.

Acquiring process of education

Learning process by the human mind may acquire knowledge in two ways – field dependent (FD) and field independent (FID) pathway and are domain specific [78]. So, some persons acquire knowledge in an abstractive pathway and some through realistic pathway [79]. Present day, computer helps persons to acquire skill sets to overcome the mathematical symbolism while abstractive pathway to model building gives an impetus to the realistic relevance. For SM practice, not only creative mind is required but also the realistic sense and a conscience regarding human suffering and social responsibility are needed. This is an utmost requirement not only for the development of the subject as well as for the management of human diseases [80-83]. These aspects remain mostly unexplored; possibly most of science educationists are unaware of the different facets of cognitive development of human mind. The requirements of SM may be difficult to understand by the conventional Indian educationists, as majority of them are unexposed to different facets of disciplines, implementation experience and medical or clinical scenarios. In fact, in India there is no separate policy for biomedical sciences; and are amalgamated and intermingled with biotechnology programs. As a result, different biologists, definitely with high academic calibers, are equated as biomedical professionals and hence, hold different crucial positions in different policy making bodies concerned with biomedical research. Interestingly, most of them do not have prior experience or exposure to clinical scenarios. Hence, in India, major notion for biomedical research becomes a mere academic pursuit.

SM as higher education

The major challenge of SM is not to bring different personals from diversified disciplines under the same platform, but the greater challenge is to bring different personals with different cognitive development. Possibly, practice of SM requires a unique blend of FD and FID cognitive patterns. And possibly practice of SM may also open up a new perspective in the practice of cognitive science [84,85]. With the advent of electronic computer, artificial intelligence and operation research, possibly algorithm may acquire the language of science especially in SM venture instead of mathematical symbols [34,86]. Likewise, automation along with robotic applications will make the biological experimentation skill sets insignificant [87]. In future, SB especially SM may change the whole educational paradigm into a new dimension and requires a different type of educational policy makers.

Major intension of Indian education is on the development of professionals with some defined skill sets that has been adopted since the time of independence as part of the nation-building program. This is reflected in the fact that India has focused on the development of institutes with single theme like technology, medicine, management or general academics [34]. However, this approach is far away from the global requirement of educational standard and majority of Indian universities do not possess all the faculty structures [77]. As an effect, Indian educational system focuses much on information delivery through class room activities, examines the memorization function (which are being considered as concept and knowledge); as a result excellence is equated to the skill set to solve some predefined problems within a short span of time [71,73,88]. As a consequence, students are inclined to develop cognition to produce the right answer instead of logic or reasoning. This is reflected in the practices in several institutions, where examiners are asked to produce the solved or model answers even to the short or lengthy answer type questions. It is the general trend that common people are suspicious regarding continuous evaluation process. Major intention of Indian education system is to cater education to large number of people. Hence, classroom teaching is prioritized and it becomes synonymous with mass education. However, this method is invariably far away from the practices of dialectics. Ironically, dialectics are often projected as an insult to the core discipline. Hence, Indian higher education is primarily concerned to meet the domestic demand rather global demand [50]. Exposure to real life experiences and its analysis is not

being included in Indian education system. Talking on the extension to the core discipline through MDID framework are discouraged, mocked with some blunt and callous arguments and projected as an insult to the mother discipline especially by majority of the senior members of the discipline. It is also an undeniable fact that a newer dimension is difficult to accept or understand by those senior members who have been trained through a cognitive development and practiced some paradigm for more than 30 years. However, in Indian educational structure they are a part of and hold crucial positions in different policy making bodies. As a result, objective interest of educational framework is directed to develop personnel in FD oriented skills sets that are more suited with administration and technical skills. There is no appreciable difference in the practices between school level and higher education system.

Such practices are in continuation due to occupancy of people with a FD cognitive style (this is due to the policy adopted since the time of independence). So, FD dependent skills are expressed with a feeling of pride. Importance of MDID framework is not generally understandable to general people and even to educational policy makers. Such ignorance levels is so much prevalent that people involved in educational policy making bodies do not have the sense regarding their opinion which may bring detrimental effect on the regional/national academics and ultimately to the nation building [88,89]. However, as per WHO recommendations, for providing better health care much emphasis should be put to analysis and rational policy making [53].

Knowledge generated in cognitive science, artificial intelligence and robotics indicate that majority of the administrative tasks can be handled by automation and machine; however, interestingly in Indian educational system administrators are projected as educationists. Major discussions on suspiciousness and an encouraging environment on the policing action among and between the colleagues prevail. Indirectly all these are for holding the local bureaucratic control. It is an undeniable fact that administrative powers are need to be more valued to maintain the bureaucratic control [23,50]. Interestingly, there are some tendencies among some faculty members to project themselves as pro-system to hold some administrative and regulatory positions in educational sector. Such practices are inevitably magnified at the national level initiative by UGC of making some gold standard for research publication. Though higher education requires diverse quality standards to meet a variety of needs of different stakeholders. This also enables individual institutions to experiment and innovate. Unfortunately, it is absent in the cognitive process of the decision makers of Indian higher education system and all are measured in same scale [50]. Due to unavailability of career prospect data, ad-hocism continues. In India, generally experts are selected on the basis of designation and not on the basis of research contribution. And designation depends on how many years a person spent in a substantive position. Hence there is absence of researcher or experts who have the orientation for MDID framework. In most of the cases, assessment is done on the conventional aspects and some irrelevant clerical assessments are made. So, due to absence of proper expert in MDID framework, accountability through external checks is meaningless. Moreover as major focus is on the development of FD cognitive process, so MDID programs including SB/SM program has been out of focus from the Indian higher education system [73].

SB as free discipline

All biomedical science is heavily dependent on physical and mathematical sciences for capturing data and its analysis and decision-making. Interestingly, over the last few decades, several mathematical optimizing techniques (mainly heuristic techniques) in operations research like Genetic Algorithm, Ant Colony Optimization, Neural Network, Particle Swarm Optimization etc. have been developed by borrowing concepts from biological systems. The foresaw of Karl Marx "Natural science will in time incorporate into itself the science of man, just as the science of man will incorporate into itself natural science: these will be one science" is aptly fit to the SM venture [90].

In our apprehension not only science trained personnel but also people with humanities and social science background may acquire required skill sets and knowledge for SB/SM and may be important for the management of human diseases in future. In a very recent document, it is reported that a person with a background with English literature, developed skill sets on brain anatomy, functional MRI and statistical interpretation while making research on the history of psychology and ultimately address a very important health issue that "why, in brain-processing terms, might culture be good for you (if it is)?" [91]. Realistically, it is difficult to predict how a researcher will address which question and how he/she will shape his/her research to address the problem and for that what sort of technical skills would be required cannot be pre-assigned. It may be quite possible that none of the technical skill sets as mentioned in European proposal would be required for a particular research problem, in the area of SM.

We apprehend that SM approach will blur the demarcating line between different far and unrelated disciplines in future and this is only possible while asking some serious health related problems. It is interesting to note that with the advent of computer and web technology, the concepts of industry and business have changed. Further open source movement, open access journals, scope of free blogs, different web based social and scientific media provide the necessary impetus to revolutionize the medium of knowledge exchange. Possibly through the practice of SM, with the help of automation, web and information technology the concept of health care system may change in future. In India, several universities have affiliating colleges and in those colleges there is almost no scope for research. So far different lab based subjects especially biological research is heavily dependent on laboratory infrastructure and grant money for research. Hence, some dissatisfaction prevails in research oriented undergraduate teachers. However, SB may provide the necessary opportunity to those teachers, as different facets of SB do not require any lab, grant money or infrastructure like conventional other biological disciplines; however, very important conclusions can be made with the applications of systems approaches in biology [92]. Moreover, some better understanding can be made in a quantitative terms through the use of computational methods rather empirical lab based practices of biology. For example, long-term effect of a drug or off-target toxicity cannot be predicted by lab-based experimentation [37,41,42,93-95].

Research in undergraduate medical education is also very poor in India. This has also been reflected in the comment of Indian Prime Minister Mr. Narendra Modi [96]. A report reveals that

India's global share on medical research was only 0.714% [97]. On the basis of publication record during the period of 1999- 2008, India holds 12th rank among the productive countries in medicine research consisting of 65,745 papers with a global publication share of 1.59% [98]. In India a considerable amount of medical oriented especially biomedical researches are being conducted outside of medical faculties/education system. These aforementioned reports actually considered every fields of biomedical research and had not distinguished whether such medical research are conducted outside of the medical faculties/institutions or not. In 2016 report clearly indicates that in India only 25 medical institutes out of 579 medical institutions can actively do research and publish their research findings. Interestingly these 25 medical institutes share 40.3% of the country's total research output [99]. Such poor condition is due to overwhelming clinical burden and lack of infrastructure in different medical colleges. Hence, in this situation, SM also helps to motivate a research culture in different medical colleges, as there is no dearth of patients' medical data. Therefore, we apprehend that practice of SB, especially SM can make a change in the practice of education and learning process in the medical education system in near future. So, different awareness programs for undergraduate college teachers may be helpful for expansion of SB.

Constraints and paradigm shift

To include the clinical perspective in biology or practice of biomedical sciences is difficult and a paradigm shift in educational policy is utmost needed. In majority of the Indian universities budget allotment for different subjects are being same, sometimes science disciplines get the same amount of grant as the humanities or social sciences. And budgetary allotment depends on the number of students. Some unique arguments or aberrant proposition is frequently expressed by the administrators in academia with the concept of student teacher ratio [100]. To meet the MDID framework, inter-university faculty exchange programs or trans-institutional collaborations are good and can easily be implemented for theory or lab based subjects [23]. Though such inter-institutional research collaborations are prevented by local administrative control; but for clinic-based subjects such programs are more difficult to pursue in Indian context. This is because of not only different institutional administrative structures exist between medical education and biology education but also different educational system may be the major hurdle to make it operative. In India, Biology education is exercised in university education system under the Ministry of Human Resource & Development, whereas medical education is practiced in different medical colleges under the Ministry of Health & Family Welfare [26]. It is needless to mention here that SB or SM cannot be simply equated as basic science and needs different specialties but with same passion [13]. Hence, practices of SB especially SM in existing academic institutions may not be carried out and need some separate institutions with different type of administrative controls.

MDID research with neighbouring (near) discipline is easy and is well practiced but MDID research with far discipline is a challenge and for SB/SM this is the most pre-requisite need [34]. Though such research activities are advocated by the Global Research Council to the different research granting agencies under Govt. of India, but in India such activity is either not encouraged or encouraged with some vague propositions [91].

Another problem of conducting research programs with MDID framework is due to persistence of ascribing Ph.D. degree with faculty nomenclature. Though across the globe, people from engineering disciplines are actively engaged in SB research and SB becomes the part of engineering curriculum, but policy makers of Indian engineering education systems are not aware about these facts [46,101-103]. Hence, in India this becomes a major issue in the recruitment policy especially in engineering discipline. It is of general trend that students generally avoid programs with MDID nature due to insecurity of getting jobs in future [34].

Practices in academia

In Indian context, a good amount of money is utilized for conducting meetings in educational sector. To improve the condition of science in India, policy was developed for faculty exchange program [104]. A good number of people go for exchange program, make foreign visits. Undoubtedly, several good publications with very high impact factor are produced out of such programs, but the irony is that the same person cannot produce or fail to produce consistently even a low impact factor publication or even publication with ISBN/ISSN number after returning to home land and societal contribution or even national level contribution remains a distant dream. Even majority of persons with foreign doctoral degree unable to solve local problems, continuation of their researches is just an imposition of foreign problem to Indian context. Hence, "there are marked inequities in relation to the burden of disease and the geographic distribution of research" [105]. Development of several national level health research institutes with a single theme may be another cause of such discrepancies and/or recruitment policy for not selection of persons to his/her parent institutes. Contrary to lab based science practices, disease related research requires a pre-requisite of domain knowledge. Interestingly, the concept of domain knowledge is not understandable to Indian science policy makers and recruiters [34]. A good number of people in higher education survive by writing popular articles and getting involved in popularization of science. Popularization of science by higher education academicians is another peculiar inclination in Indian academics, possibly this provides a way-out from real problems and/or some solace to the sensitive minds. The outreach societal activity of a university is commonly seen and encouraged as arrangement of seminars lectures with popular mode that invariably carries no sense of dialectics. It is commonly seen that majority of the persons involved in academic administration fail to maintain any consistency in research activity and whatever research publications they produce are either survey based work or as a part of another research group specially with foreign collaboration [71,105]. If they produce several research publications, but with an extent of huge grant money. To avoid such misutilisation of public money, only young people would be encouraged for exchange programs and web based technologies should be utilized for conducting meetings in academics. For choosing a person for different policy making bodies in educational sector, their present research ability should be judged and while judgment some parameters need to set with respect

to the amount of grant money utilized (like an investment) for each of the research output. If such activities are not implemented, then academics will suffer. It is needless to point out here that in India getting of research grant is questionable and discussed recently [34]. An alarming report is published in 2010 that a major grant is sanctioned to academicians "from six Indian science academies" based on a research proposal which is "simply cut-and-pasted text from a previous publication" [71]. From Chaos theory, it is now known that some local issues are vital in an understanding of a system dynamics. Human health is a dynamical system and hence its management can be better solved if there is an understanding of regional and local issues in a dynamical manner. But surprisingly a recent report indicates that there are marked inequities in relation to the burden of disease and geographic distribution of research [105]. This also indicates an anomaly of recruitment policy developed in an ad-hoc manner as discussed very recent time [34]. Hence, major emphasis should be given on research outputs that are being conducted within the homeland. Much emphasis should be given on collaboration within country, and for this, some administrative support and flexibility is needed.

Undoubtedly a lifelong training is needed for venture into SB or SM work. In India, several faculty improvement courses are conducted as refresher courses that actually do not help faculties in their research, as majority of those programs curriculum are devoid of any hands-on training or applicative part. Most of the refresher courses are oriented with mere lectures that only provide information. Realistically, in today's web based world, one can easily retrieve those information through web search if one wants to. However, attending some of those refresher courses is mandatory for university faculty members for getting promotions in job. Majority of the refresher courses are discipline directed and allow only discipline-based personnel, so majority of the participants (especially Ph.D. holders) almost know everything regarding methodologies behind the research topics that are being delivered in the refresher courses. In lieu of that a hands-on training programs are needed to develop for venturing into the subjects with MDID nature especially in SB/SM.

A review report published in 2005 also clearly indicates that NGOs can make strong and lasting inroads into reducing the disease burden of the world's most affected populations through effective research action [106]. Since the time of pre-independence this had been practiced. The notable example is the development of Indian Association for Cultivation of Science by Dr. Mahendralal Sarkar and this society helped India to win only single Noble prize to Indian science by the Indian origin. Presently, in India, people generally become encouraged with the establishment directed academics, but scientific society or free type academics is unappreciated and regarded as waste of time. Several seminar sessions are being conducted in Society for Systems Biology & Translational Research on different topics having MDID nature; however, as there is no incentive, so very few people even from academics attend such seminar sessions. Though at present moment, people can understand and become pro-active for any welfare society or politically directed society; however, scientific research society is not very popular in India. Such differences in attitude are due to penetration of only FD type of cognition.

It is needless to point out here that a different cognitive style may be needed to explore in the areas of research with MDID nature and that is needed from early childhood. So we appreciate the European proposal of inclusions of systems level understanding of biology at the school level; however, with an inclusion in research/creative mode. An initiative of inclusion of one subject in school covering the methodology of retrieving information on different facets of MDID nature from web (not only SB/SM) may be beneficial for the development of mindset of the future generation towards MDID subjects.

Concluding remarks

The idea of Rainer Breitling, University of Glasglow "a generous openness towards new ideas is required to provide all the intellectual tools to sustain a research area with as wide a scope as systems biology" is more applicable for developing countries especially for India, and to avoid the criticism as "one of those hypes", SM would be the inevitable outcome of SB venture. Imposition of European proposal on the streamlining approach of SB needs much more money; and India (and other developing countries) possibly cannot afford this due to associated sophisticated technology. With the commodity and commercialization approach towards health care, though some fragmented research can be produced; however, health care system of India may not be able to implement this aspect of SB due to associated huge cost, as existing medical cost is itself unbearable to the poor patients of India. This may be true for other developing countries as well. Even in the high income country such as UK, it is observed that within a country there is a gross difference in the average life-span by some 28 years, depending on whether a person is in the poorer or wealthier strata of society [53].

However, contrary to the western world, there is enormous possibility to get clinical data of Indian patients provided some administrative and managerial reforms in academics and health care systems are allowed. Proper implementation of SB, especially in SM, a research or problem oriented approach could be the ideal. In this connection, Sir Michael Marmot, Chair of the Commission on Social Determinants of Health, World Health Organization, may be noted: "The key determinants of health of individuals and populations are the circumstances in which people are born, grow, live, work and age, and those circumstances are affected by the social and economic environment. They are the premature cause of disease and suffering; that's unnecessary. And that's why we say a toxic combination of poor social policies, bad politics and unfair economics are causing health and disease on a grand scale." Hence, India's needs and experiences on SM would be helpful for the development of SM in other developing countries. Moreover, if once it is implemented in India, then generation of large public health database may be a good initiative for understanding of preventive medicine and sustainable of health care practices with low cost.

It may not be irrelevant to note here that although sometimes used interchangeably, there is a sharp and fine difference between 'administrative reforms' and 'managerial reforms'. 'Administration' is a top-level determinative or thinking function, which is mainly concerned with the determination of major objectives and policies; whereas 'Management' is largely middle and lower level executive

function which is mainly concerned with the implementation of policies. Furthermore, administrative decisions are mostly influenced by public opinion and other outside forces and are not directly concerned with direction of human efforts. However, managerial decisions are mainly influenced by objectives and policies of the organization, and are actively concerned with direction of human efforts in the execution of plans [107]. To venture into SM, admixtures of creative talent with patients care management skill set are essential, and for this witness to clinical problems are the essential pre-requisite.

For successful implementation of SM, funding from public sector is essential but without government control [23]. For developing countries already Middle-out Rationalist Approach (MORA) is proposed and a considerable number of research works with respect to cancer has already been done [11,12]. However, towards the trials of SM, new institutes are utmost needed with some fresh personals who are trained with creativity in human health care research directly but with an MDID framework in native land. We hope that such venture will make a paradigm shift in education and health care system and able to show some newer avenues to the world.

Acknowledgement

This is the outcome of discussions by several members of Society for Systems Biology & Translational Research (SSBTR) at SSBTR office at 103, Block – C, Bangur Avenue, Kolkata 700 055.

References

1. Kirschner MW (2005) The meaning of systems biology Cell 121: 503-504.
2. Breitling R (2010) What is systems biology. Frontiers in Physiology 1: 9.
3. Weston AD, Hood L (2004) Systems Biology, Proteomics, and the Future of Health Care: Toward Predictive, Preventative, and Personalized Medicine. J Proteome Res 3: 179-196.
4. Liu ET (2005) Integrative Biology and Systems Biology. Mol Syst Biol 0004.
5. Workshop Report (2006) Philosophical Issues in Systems Biology. University of Exeter.
6. Ahn AC, Tewari M, Poon CS, Phillips RS (2006) The Limits of Reductionism in Medicine: Could Systems Biology Offer an Alternative? PloS Med 3: e208.
7. Ahn AC, Tewari M, Poon CS, Phillips RS (2006) The Limits of Reductionism in Medicine: Could Systems Biology Offer an Alternative? PloS Med 3: 0030208.
8. Majumder D (2009) Medicine can meet with engineering: Informatics at the cross-road. Technorama 58. 7–20.
9. Federoff HJ, Gostin LO (2009) Evolving from reductionism to holism: is there a future for systems medicine? JAMA 302: 994–996.
10. Henry CM. Chemical and Engineering News, American Chemical Society, 8120, url: www.pubs.acs.org/cen/coverstory/8120/8120biology.html.
11. Majumder D, Mukherjee A (2011) A passage through systems biology to systems medicine: adoption of middle-out rational approaches towards the understanding of clinical outcome in cancer therapy. Analyst 136: 663-678.
12. Majumder D, Mukherjee A (2013) Multi-scale modeling approaches in Systems Biology towards the assessment of cancer treatment dynamics: adoption of Middle-out Rationalist Approach. Advances in Cancer: Research & Treatment 587889.
13. Wolkenhauer O, Auffray C, Jaster R, Steinhoff G, Dammann O (2013) The road from systems biology to systems medicine. Pediatr Res 73: 502-507.
14. Alwan A (2011) Global status report on noncommunicable diseases. World Health Organization.
15. Kirschner M (2016) Systems medicine: sketching the landscape, Ch 1, In: Systems Medicine, Wolkenhauer O, Schmitz U (Eds.), Humana Press, New York, London, Heidelberg 3-16.
16. Global Health Overview, GlobalIssues, 588, url: www.globalissues.org/article/588/global-health-overview.
17. Federal Ministry of Education and Research (2012) Paving the Way for Systems Medicine. The e: Med research and funding concept.
18. Schork NJ (2015) Time for one-person trials. Nature 520: 609-611.
19. SAARC, url: www.saarc-sec.org.
20. Sahay R, Lim CH, Sumi C, Walsh JP, Schiff JA (2015) The future of Asian finance. IMF, International Monetary Fund. ISBN: 978-1-49831-719-1.
21. FICCI Higher Education Summit 2014 report.
22. Azim Majumder MA, Shaban SF, Rahman S, Rahman N, Ahmed M, et al. (2012) PubMed-based quantitative analysis of biomedical publications in the SAARC countries: 1985-2009. J Coll Physicians Surg Pak 22: 560–564.
23. Joseph M, Robin A (2014) Free Indian science. 508: 36-38.
24. Mondal S, Abrol D (2015) Clinical trials industry in India: A systematic Review. Institute for Studies in Industrial Development, New Delhi.
25. Ravinetto R (2016) Methodological and ethical challenges in non-commercial North-South collaborative clinical trials, PhD thesis, Leuven University Press 82.
26. Berghmans S, Bisagni A, Bouillon R (2011) A Stronger Biomedical Research for a Better European Future, White Paper II, European Medical Research Councils (EMRC), European Science Foundation. 24.
27. Carr D (2004) Improving the health of the World's poorest people, Population Reference Bureau. Celebrating 75 years 1929-2004.
28. (2015) Nature Science in India, Nature 521: 141.
29. (2015) All India Survey on Higher Education.
30. Berghmans S, Bisagni A, Bouillon R (2011) A Stronger Biomedical Research for a Better European Future, White Paper II, European Medical Research Councils (EMRC), European Science Foundation, ISBN: 978-2-918428-35-0 24.
31. (2013) All India Survey on Higher Education.
32. Joseph MI, Robin A (2014) Free Indian science. Nature 508: 36-38.
33. (2015) IMF, International Monetary Fund, url: www.imf.org/.
34. Majumder D, Banerjee A, Ray DK, Naskar TK, Chatterjee I, et al. (2016) Bottleneck towards the Practice of Multi-/Interdisciplinary Nature of Systems Pharmacology and Systems Medicine: Experience from India, Adv Pharmacol Clin Tria. 1: APCT-MS-ID-000102.
35. (2014) Indo US Conference and Workshop on Synthetic and Systems Biology, November 9-12.
36. Mukherjee A, Icbal A, Majumder D (2006) Exploring the effectiveness of low continuous chemo-bio-therapeutic treatment of cancer through analytical system modelling. J Biol Syst 14: 1-12.
37. Majumder D, Mukherjee A (2006) Patho-physiologically based logistics for the treatment of cancer. J Biol Syst 14: 631-650.
38. Dutta HK (2015) Metronomic chemotherapy: an alternative and effective means of chemotherapy, ideal for developing countries (Editorial). JASA 22: 3-5.
39. Kerr DJ, Midgley R (2010) Can We Treat Cancer for a Dollar a Day? Guidelines for Low-Income Countries. N Engl J Med 26: 363: 801-803.

40. Bertolini F, Sukhatme VP, Bouche G (2015) Drug repurposing in oncology-patient and health systems opportunities. Nat Rev Clin Oncol 12: 732–742.

41. Majumder D, Mukherjee A (2007) Mathematical modeling of toxicity related trade-offs in metronomic chemotherapy IET Systems Biology 1: 298-305.

42. Mukherjee A, Majumder D (2008) Mathematical modelling for the assessment of the effect of drug application delays in metronomic chemotherapy of cancer due to physiological constraints. BioSystems 91: 108-116.

43. Nosengo N (2016) Can you teach old drugs new tricks? Nature 534: 314-316.

44. Pemovska T, Ostling P, Heckman C, Kallioniemi O, Wennerberg K (2015) Individualised systems medicine: Next-generation precision cancer medicine and drug positioning. Drug Discov World 16: 47-53.

45. Global Research Council (2016), url: http://www.rcuk.ac.uk/documents/documents/GRC2016Interdisciplinarity-pdf/.

46. Cvijovic M, Thomas H, Jure A, Lilia A, Eivind A, et al. (2016) Strategies for structuring interdisciplinary education in Systems Biology: an European perspective, Syst Biol Appl 2: 16011.

47. Report of the Planning Commission (2011) 12th Five year plan, Systems and Synthetic Biology Resource Network. DST, Govt. of India.

48. Young D, Stark J, Kirschner D (2008) Systems biology of persistent infection: tuberculosis as a case study. Nat Rev Microbiol 6: 520–528.

49. Report of the Planning Commission (2011) 12th Five year plan, Report of the Working Group on Health Research for the 12th Five Year Plan, Department of Health, Govt. of India.

50. Agarwal P (2006) Higher education in India: Need for change, working paper no. 180. Indian Council for Research on International Economic Relations.

51. Ledford H (2015) Team Science. Nature 525: 308-311.

52. Powell A, O'Malley MA, Müller-Wille S, Calvert J, Dupré J (2007) Disciplinary Baptisms: A Comparison of the Naming Stories of Genetics, Molecular Biology, Genomics, and Systems Biology. Hist Philos Life Sci 29: 5-32.

53. CSHD (2008) Closing the gap in generation: Health equity through action on the social determinants of health, Commission on Social Determinants on Health, World Health Organization, Geneva.

54. The Gazette in India (2016) Part III, Section 4.

55. Gewin V (2014) Break out. Nature 511:371-373.

56. Muthuswamy V (2016) Ethical issues in international collaborative research. An Indian perspective. TRUST eNewsletter 1: 1-2.

57. Denburg AE, Joffe S, Gupta S, Howard SC, Ribeiro RC, et al. (2012) Pediatric Oncology Research in Low Income Countries: Ethical Concepts and Challenges. Pediatr Blood Cancer 58: 492-497.

58. Dyer J (2015) The Age of transition and scientistic fraud. Global Research, Canada 5470656.

59. Wolkenhauer O, Ullah M, Wellstead P, Cho KH (2005) The dynamic systems approach to control and regulation of intercellular networks. FEBS Letters 579: 1846-1853.

60. Kline M (1977) The conflict between research and teaching, Chapter 4. In: Why professors cannot teach, St. Martin's Press.

61. Hyman JS, Jacobs LF (2010) 10 reasons to go to a research university, Professors' Guide.

62. Dubbudu R (2015) 35% Faculty positions vacant in Government Higher Education Institutes, Factly March 26.

63. Varma S (2013) Indian Higher Education: 40% of college teachers' temporary, quality of learning badly hit, Times of India November 10.

64. Georgetown University, url: https://systemsmedicine.georgetown.edu/MD-MSprogram

65. Streitwieser B, Ogden AC (2016) The Scholar-Practitioner Debate in International Higher Education. Int Higher Edu 86: 6-8.

66. Bagcchi S (2015) India has low doctor to patient ratio. BMJ 351: h5195.

67. Sood R, Adkoli BV (2000) Medical Education in India-Problems and Prospects. Journal of Indian Academy of Clinical Medicine 1: 210-212.

68. National Knowledge Commission: Report to the Nation (2006-2009). Government of India.

69. Pathak V (2016) UGC told to retain teaching workloads, The Hindu May 27.

70. Pathak V (2016) Tight norms soon for journal publications, The Hindu May 28.

71. Chaurasia A (2016) Stop teaching Indians to copy and paste. Nature 534: 591.

72. GaanZone (2012) The educational system is killing creativity in Indian children.

73. India Today (2014) Education system in India discourages creativity: Educationist Soumitra Dutta, April 1

74. Kala L, Ramadas J (2001) History and Philosophy of Science, Cognitive Science and Science Education: Issues at the Interface. Ind Education Rev 37: 1.

75. Onarheim B, Friis-Olivarius M (2013) Applying the neuroscience of creativity to creativity training. Front Hum Neurosci 7: 656.

76. India Today (2016) Top Indian universities, May 7, url: http://indiatoday.intoday.in/education/story/top-indian-universities/1/660951.html

77. Viswanathan B, Quora, url: https://www.quora.com/Why-is-there-not-a-single-Indian-university-within-the-worlds-top-100-index-list.

78. Pithers RT (2002) Cognitive Learning Style: a review of the field dependent-field independent approach. J Vocation Edu Train 54: 117-132.

79. Kala L, Ramadas J (2001) History and philosophy of science, cognitive science and science education: Issues at the Interface. Ind Edu Rev 37: 1.

80. Kaplan RM, Satterfield JM, Kington RS (2012) Building a better physician - the case for the new MCAT. N Engl J Med 366: 1265-1268.

81. Iris F (2012) Psychiatric Systems Medicine: Closer at hand than anticipated but not with the expected portrait. Pharmacosychiatry 45: S12-S21.

82. Mitchell ES, Conus N, Kaput J (2014) B vitamin polymorphisms and behavior: Evidence of associations with neurodevelopment, depression, schizophrenia, bipolar disorder and cognitive decline. Neurosci Biobehav Rev 47: 307-320.

83. Haniff D, Chamberlain A, Moody L, De Freitas S (2014) Virtual environments for mental health issues: A review. J Metabolom Syst Biol 3: 1-10.

84. Bilder RM, Knudsen KS (2014) Creative cognition and systems biology on the edge of chaos. Front Psychol 5: 1104.

85. Wiggins GA, Bhattacharya J (2014) Mind the gap: an attempt to bridge computational and neuroscientific approaches to study creativity. Front Hum Neurosci 8: 540.

86. Kitano H (2015) Accelerating systems biology research and its real world deployment. Syst Biol Appl 1: 15009.

87. Griffin A (2015) This `psychic robot' can read your mind, The Times of India, Kolkata, October 9.

88. Khalakdina M (2008) The Development of critical skills. In: Human Development in the Indian Context: A Socio-Cultural Focus. I: 259-310, Sage Publisher, London, Los Angeles, New Delhi, Singapore.

89. Prince MJ, Felder RM, Brent R (2007) Does faculty research improve undergraduate teaching? An analysis of existing and potential synergies. J Engg Educ 96: 283-294.

90. Pekelis V (1987) Note from the compiler. In: Cybernetics of Living Matter: Nature, Man, Information, Makarov IM (Ed.), MIR Publishers, Moscow.

91. Rylance R (2015) Global funders to focus on inter disciplinarity. Nature 525: 313-315.

92. Islam MM (2013) Role of bioinformatics in developing country: Bangladesh. Curr Trend Technol Sci 2: 160-165.

93. Mukherjee S, Majumder D (2009) Computational molecular docking assessment of hormone receptor adjuvant drugs: Breast cancer as an example. Pathophysiol 16: 19-29.

94. Dhar PK, Majumder D (2015) Development of the Analytical Model for the Assessment of the Efficiencies of Different Therapeutic Modalities in Leukemia. J Comput Syst Biol 1: 104.

95. Mukherjee S, Chatterjee G, Ghosh M, Das B, Majumder D (2016) Efficacy and Toxicity Assessment of Different Antibody Based Antiangiogenic Drugs by Computational Docking Method. Adv Bioinform 7053712.

96. Times of India (2014) PM Narendra Modi: India lagging behind medical research, October 20.

97. Deo MG (2008) Undergraduate medical students' research in India. J Postgrad Med 54: 176-179.

98. Gupta BM, Bala A (2011) A scientometric analysis of Indian research output in medicine during 1999-2008. J Nat Sci Biol Med 2: 87-100.

99. Nagarajan R (2015) Study reveals poor state of medical research. Times of India, April 21.

100. Staff reporter (2016) Protest against UGC notification, The Hindu May 31.

101. Sontag ED (2004) Some new directions in control theory inspired by systems biology. IET Syst Biol 1: 9-18.

102. Idekar T, Winslow R, Lauffenburger AD (2006) Bioengineering and Systems Biology. Annal Biomed Engg 34: 257-264.

103. Wellsted P (2007) The Rôle of Control and System Theory in Systems Biology. 10th International Federation for Automatic Control (IFAC). 1-33.

104. Jayaraman KS (2012) Indian science in need of overhaul, Nature January 6.

105. Kalita A, Shinde S, Patel V (2015) Public health research in India in the new millennium: a bibliometric analysis. Global Health Action 8: 27576.

106. Delisle H, Roberts JH, Munro M, Jones L, Gyorkos TW (2005) The role of NGOs in global health research for development. Health Res Policy Syst 3: 3.

107. Koontz H, Weihrich H (2005) Essentials of Management, TMH, New Delhi. Gupta CB, 2002, Management Theory and Practice. Sultan Chand and Sons. New Delhi.

Citation: *Majumder D, Ray DK, Chatterjee I, Gupta RK, Mukherjee A, et al. (2016) Importance and Implementation Strategies of Systems Medicine Education in India. Ann Syst Biol 1(1): 001-012.*