Philosophy of modern bioengineering

Article *in* IIUM Engineering Journal · December 2017

DOI: 10.31436/iiumej.v18i2.723

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PHILOSOPHY OF MODERN BIOENGINEERING

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(Received: 25th Aug. 2016; Accepted: 5th May 2015; Published on-line: 31st Dec. 2017)

ABSTRACT: This article investigates the philosophical foundations of modern bioengineering to articulate its rational framework. Engineering, as an ultimate mechanism to transform knowledge into practice, is essential for both physical and biological sciences. It reduces data, concepts, and designs to pictorial forms. Integration of engineering with newly emerging biosciences, has presented a unique opportunity to overcome major challenges to environmental ecology and human health. To harness the potential of modern bioengineering and establish a sustainable foundation for green technology, scientists and engineers should be acquainted with the normative questions of science and technology. Besides acquiring the general principles of scientific research and identification of the intrinsic goals of the endeavor, philosophy of bioengineering exposes scientists to both the descriptive '*how*' questions of the physical world as well as the normative '*why*' questions of values. Such an interdisciplinary approach is essential, not only for inspiration to acquire the genuine knowledge, but also to expose the scientists and bioengineers to their ethical and social responsibilities. Introducing the conceptual framework of bioengineering, this paper has investigated the three major philosophies that have been dominating the basic presuppositions of the scientific research method in the modern history of science, namely: (i) the mechanical approach of physical sciences, (ii) the functional (goal-guided) approach of biological processes, and (iii) the integrated approach. The paper also has conducted an analytical study on various branches of the emerging discipline of bioscience. It has concluded that adopting the interdisciplinary approach is essential to harness potentials of bioengineering and to establish foundations of green technology based on moral values. To materialize such a noble goal, both epistemological and normative knowledge must be acquired in bioengineering research and education. The former is essential for invention and innovation; while the latter exposes bioengineers to their ethical and moral commitments.

ABSTRAK: Artikel ini mengkaji tentang falsafah asas bidang biokejuruteraan moden bagi menjelaskan rangka kerja rasional. Bidang kejuruteraan adalah mekanisma muktamad untuk mengubah ilmu kepada aplikasi, penting bagi kedua-dua sains fizikal dan sains biologi. Ia mengurangkan data, konsep dan rekaan kepada bentuk bergambar. Integrasi kejuruteraan bersama kemunculan biosains baharu, telah memberi peluang yang unik untuk mengatasi cabaran utama yang dihadapi oleh ekologi persekitatan dan kesihatan manusia. Bagi memanfaatkan potensi biokejuruteraan moden dan membina asas kukuh pada teknologi hijau, saintis dan jurutera sepatutnya mengetahui soalan normatif tentang sains dan teknologi. Selain mendapatkan prinsip umum kajian saintifik dan mengenal pasti matlamat intrisik bagi usaha ini. Falsafah biokejuruteraan mendedahkan saintis kepada dua deskriptif soalan *'bagaimana'* pada dunia fizikal serta soalan normatif *'mengapa'* pada nilai-nilai. Kepentingan kaedah interdisiplinari ini bukan sahaja memberi inspirasi bagi menambah ilmu yang tulen, malah mendedahkan kepada saintis dan bio-jurutera kepada tanggungjawab etika dan sosial. Melalui pendedahan konsep struktur biokejuruteraan, kertas ini telah mengkaji tiga falsafah penting yang mendominasi pengetahuan asas kaedah kajian saintifik dalam sejarah moden sains, seperti berikut: (i) kaedah mekanikal sains fizikal, (ii) pendekatan berfungsi (berpandukan-matlamat) proses biologi, dan (iii) pendekatan bersepadu. Kertas ini juga telah menjalankan kajian analitikal terhadap pelbagai cabang kemunculan disiplin biosains. Sebagai rumusan, pendekatan multidisiplin adalah sangat penting diamalkan untuk manfaat potensi biokejuruteraan dan membina asas teknologi hijau berdasarkan nilai moral. Bagi merialisasi matlamat mulia ini, kedua-dua ilmu epistemologikal dan normatif mesti di pelajari dalam penyelidikan biokejuruteraan dan pelajaran. Ilmu epistemologikal penting bagi ciptaan dan inovasi, sementara ilmu normatif mendedahkan bio-jurutera kepada komitmen etika dan moral.

KEYWORDS: *philosophy; bioengineering; integrated approach; systems biology; goal-directed process; causal explanation; ethics*

1. INTRODUCTION

In its ambitious plan for a bioengineering research programme in the 21st century, Harvard University emphasizes that there is enormous potential for transformation of bioengineering into a discipline directed toward synthesis of technologies that have profound impact on human well-being and the future of the planet earth. The plan further explains that bioengineering is an exciting, deeply interdisciplinary, intellectual area that naturally integrates physical, life sciences, and information sciences to understand complicated biological systems. It is the basic point of intellectual integration for engineering, medicine, molecular biology, chemistry, synthetic biology, bio-energy, systems biology, stem cell research and biological computation[1].

The interdisciplinary approach that integrates engineering with biological and physical sciences is becoming the central issue of the modern philosophy of science. It presents a unique opportunity for scientific enterprise to develop methods to enhance human health and protect the natural environment. Harnessing such opportunities to tackle challenges posted by ecological crises represents the great advantage of bioengineering science, which promotes the integrated approach. For this purpose, scientists, engineers, philosophers and theologians need a constructive team collaboration to sustain natural recourses and bring better chances for life on planet earth.

Integration of the two traditional methods of scientific explanation is one of the major objectives of philosophy of bioengineering. The *causal* and *teleological* explanations are the dominating philosophies of scientific inquiry in the modern history of science[2]. Modern philosophy of science presupposes that processes of the physical world are *mechanical* and *deterministic* in nature, while biological processes are *functional* and *purposive* (goal-guided). Thus, the causal explanation is mainly concerned with the physical world, while the teleological explanation deals with the goal-directed processes of biological and behavioral organisms. The key difference between the two modes of

[1] See details at
https://hms.harvard.edu/sites/default/files/assets/About_Us/Off_Dean/files/Bioengineer.pdf

[2] The teleological explanation in fact finds its roots and origins in ancient Greek philosophy, therefore it should be understood in two contexts: (i) in the context of classical philosophy that interprets the entire phenomena of the world based on purpose and function; and (ii) in the context of modern philosophy that applies the concept on biological and purposive processes / actions of organisms or systems.

explanation lies in the circumstance under which cause and effect are related to each other. In goal-guided processes of biology, the future (the goal) plays a major role to determine the present act, while in causal explanation of the physical processes the past explains the present and determines the future act [13, 20].

The major characteristic of biological systems is that they are brought about by interactions of their parts but these parts in isolation display no similar characteristics of their components! In other words, it is hard to predict the behavior of biological processes from knowledge of their individual parts [17]. This profound difference between the physical and biological worlds has critical impacts on their methods of investigation and understanding. Biological systems are too complex to be explained fully by the method of physical sciences, which has been remarkably successful in developing approaches to understand and control the physical world[3]. Mathematical modeling and computer simulations play a crucial role to understand the internal nature and dynamics of biological processes to arrive at predictions about their structural development and the effect of their interactions with the environment [17].

In contrast to the classical philosophies, the integrated approach presumes no essential difference between motivational explanation in biology and causal explanation in physics. Physical and biological processes, according to the integrated method, can be approached either by the causal explanation, as emphasized by Carl G. Hempel and Paul Oppenheim [13], or through application of teleological method on physical sciences, as perfectly presented by producing goal-directed systems, such as plastic missiles. The scientific advancements in the first half of the Twentieth Century, especially during World War II, brought to scientists' attention the practical value of teleological explanation to develop goal-guided systems to communicate and control biological as well as physical systems. This transdisciplinary approach has become known as '*Cybernetics*'. One of the fundamental works on this method is the work of eminent mathematician Norbert Wiener, entitled "*Cybernetics*", published in 1948[4].

It is evidently clear that biological processes constitute the basic part of the integrated approach of contemporary philosophy of science. Articulation of the philosophical foundations of bioscience, understanding its rational framework, the formulation of its principles, and developing the relevant approaches to understand the complex systems of life is, therefore, becoming the major objective of the modern philosophy of science. These are the basic themes that this paper aims to highlight. Through reflection on philosophical foundations of bioengineering, this paper aims at articulating fundamentals of the integrated approach. It also investigates the ethical concerns of bioengineering research and practice. The basic content of paper is divided into three major parts, including the conceptual framework, the philosophical foundations of bioengineering, and ethical concerns of bioengineering where the Islamic perspective on the negative impacts of bioresearch will be presented. Conclusions and findings of the paper are found in the final section.

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[3] In their preface, the authors of "*Systems Biology: A Textbook*" remark that 'life is probably the most complex phenomenon in the universe'. This statement, and other researcher's view on biology, emphasize that there are more practical questions to be answered by systems biologists, such as what is life, and why do we age and die?

[4] The full title of the book is "*Cybernetics* Or *Control and Communication in the Animal and the Machine*. It is obvious that Prof. Wiener has clarified the term "*Cybernetics*" by the other part of the title. However, it can be defined as a transdisciplinary approach for exploring regulatory systems, their structures, constraints, and possibilities.

2. THE CONCEPTUAL FRAMEWORK OF BIOENGINEERING

The term '*Science*' in modern philosophy of science, is used in three interconnected contexts: *first*, science as a systematic method of inquiry which aims at understanding the natural and human phenomena; *second*, science as an accumulative body of acquired knowledge[5]; and *third*, science as an application of knowledge. '*Bioengineering'* is the interdisciplinary approach that related to the third meaning. It can be defined as *the application of method of physical sciences and mathematical principles to understand the complex systems of life for practical purposes*. Bioengineering encompasses various sciences which integrate engineering and life science and its applications, such as biomedical engineering, bioinformatics, and systems biology. In contrast to the conventional concept of '*biology*', biosciences are mainly practical. In education, engineering largely aims at developing skills and abilities of conceptualization and calculation, whereas biology education develops the descriptive and connective abilities [15]. The common objective of biosciences, however, is to understand the complex systems of life for practical ends.

A comparative and analytical study on bioengineering reveals that it works in collaboration with other fields, especially with systems biology and bioinformatics. The set of bioscience can be divided, based on their final objectives, into two major groups[6]: the first group constitutes an effective method of analyzing to understand the complex systems of life, while the other group concerns with application of the cumulative knowledge. The first group aims to produce knowledge through collection and analytical study of data; while the other group aims at transforming the existing knowledge into practice. For example, bioinformatics and systems biology are concerned with building databases, analysis, and the molding of complexities of the biological phenomenon for proper understanding of the phenomena. Bioengineering and biomedical engineering, on the other hand, are concerned with application of knowledge to produce technologies and to develop methods that promote human well-being and sustain the environmental health.

2.1 The Analytic Approaches

We are using the term '*analytic*' to describe biosciences concerned with collection, analyzing and modeling of biological data for practical ends. The term should not indicate that these sciences are less practical than '*applied*' sciences; rather it emphasizes that such sciences are effective methods or useful tools to create databases for understanding the complex systems of life. Among many types of biosciences, *bioinformatics* and *systems biology* might be regarded as key elements of analytical approaches that are capable of providing relevant methods which enable bioengineers to build systematic databases and access various forms of biological systems for explanation and understanding. Both depend on mathematics and computer science as major tools for analysis, designing and modeling.

[5] With regard to the cumulative body of knowledge, scientific inquiry, according to Arthur A. Noyes, has two distinctive objectives: *first*, science aims at making the comprehension of the existing knowledge that already acquired by mankind as easy as possible; *second*, it aims to add to the total sum of human knowledge by the discovery of previously unknown phenomena. [Noyes, Arthur A., (1902). *The General Principles of Physical Science.* (Henry Holt and Company, New York), p3-4.]

[6] It should be noted that these classifications are procedural to facilitate the study for better understanding; there are no real boundaries between biosciences, they overlap each other, especially in their research method.

2.1.1 Bioinformatics

Bioinformatics is an interdisciplinary science that develops methods and software tools for understanding biological data. It is the basic approach of bioscience research that is concerned with building databases and analysis. The simple view of bioinformatics science is the process of collection, storage, and analysis of biological information. As an interdisciplinary approach, *bioinformatics integrates* computer science with statistics, mathematics, and engineering to analyze and interpret biological data. Alongside the data handling, bioinformatics deals with a wide range of data that starts from simple analytical approaches that are routinely conducted by molecular biologists to find the related gene and protein sequence, through an expended mode of specialized tools for data analysis, to sophisticated statistical methods for high-throughput data analysis [12, 18].

Systems biology projects mainly rely on bioinformatics techniques and infrastructure to conduct their data analysis. Annotation of genome sequences might be regarded as one of the most basic application of bioinformatics methods. According to many biologists, such as Clair and Alistair, the bioinformatics field is moving from focus on functions of single genes to consider wider relationships between genes as they operate together in pathways and networks. In other words, bioinformatics is increasingly considering the questions of molecular systems biology; therefore, the question may arise about the real contribution of bioinformatics to the new emerging science of systems biology. The practical cases show that bioinformatics can serve systems biology in many ways, but two of the most basic forms are that: *first*, bioinformatics provides methods to obtain systems information from the vast amount of available databases that constitute the basic infrastructure for analysis and generating new data. *Second*, in the context of data handling, bioinformatics is regarded as an important method which concerned with designing the appropriate standards and databases for proper archiving[12].

2.1.2 Systems Biology

What is *systems biology*, how does it work, and why is it important? Such questions are important to understand the emerging approach to interpret the biological phenomenon that encompasses various methods of explanation. Biological systems like organisms, cells, or biomolecules are highly organized in their structure and function. Biologists have developed different approaches to explain and understand such systems. Systems biology, however, might be regarded as one of the most effective and promising approaches to understand the complex systems and mysterious behaviors of biological phenomena. It integrates various methods to develop a qualitative and quantitative understanding, such as experiment and modeling on one hand and mathematical and computational analysis on the other. These characteristics qualify systems biology as an effective method to understand the complexity of life. By studying the structure and physiology of living systems in detail, researchers from different disciplines have discovered how the mystery of life arises from the structure and functional organization of cells and from the continuous refinement by mutation and selection[17].

There are, however, still many critical questions that biologists need to deal with, such as the problem of aging and death. Authors of "*Systems Biology: A Textbook*" believe that systems biology is the key to answer many questions of biology. They explain that systems biology is the combined study of biological systems which aims at: (i) investigating the components of cellular networks and their interactions; (ii) applying experimental high-throughput and whole-genome techniques; and (iii) integrating computational method with experimental efforts[17]. Klipp and her colleagues have summarized the major factors behind the flourishing of systems biology. They emphasize that the systemic approach in biology is not new, but it recently gained new thrust due to the emergence of powerful experimental and computational methods. It is based on the accumulation of an increasingly detailed biological knowledge, on the emergence of new experimental techniques in genomics and proteomics, tradition of mathematical modeling of biological processes, the exponentially growing computer power, as prerequisite for databases and the calculation of large systems, and on the internet as the central medium for a quick and comprehensive exchange of information [17].

A systemic approach to life sciences research is necessary for better qualitative and quantitative understanding of the functioning of biological systems in health and pathological conditions. The ultimate goal of systems biology is to understand the structure and function of physiological and patho-physiological systems, to develop fruitful approaches in biotechnology. For example, knowledge gained from systems biology can open up the way for disease control, prevention and treatment. Systems biology has great benefits since a thorough understanding of complex biological processes will allow tackling of many real problems, especially in relation to health sciences. In providing solutions to such practical problems, systems biology is regarded as the key approach towards understanding secrets of life for practical purposes in the twenty first century[18].

2.2 The Applied Approaches

The process of engineering, in any product, is usually composed of three parts: analysis, synthesis, and design. Analysis is the study of systems in order to understand their function. Synthesis is the practical building of the systems under analysis. Both steps contribute to the end goal of engineering, which lies in the final design of the product. The useful approaches of bioscience are that which have a practical value in transforming the theoretical knowledge into technologies and practical methods. Bioengineering and biomedical engineering are the two most practical aspects of bioscience. Both aim at employing biological knowledge for practical purposes, such as producing and using artificial tools to enhance human health, and using organisms and biological processes in industry. Some researchers view these two effective approaches of bioscience as the same, in the sense that biomedical engineering is a specific form of bioengineering that concerns itself with medical and health sciences. However, others treat these two sciences as different disciplines. They emphasize that, while bioengineering is concerned with developing tools and technologies, biomedical engineering aims at practical application of those technologies for health care purposes[7].

2.2.1 Bioengineering

According to Arthur Johnson, bioengineering does not imply a particular application or industry. In this sense it differs from biomedical engineering, environmental engineering, or agricultural engineering, each of which applies knowledge about biology to particular application areas. The term 'bioengineering'[8] or biological engineering is used for the interdisciplinary approach that integrates physical sciences with life sciences in the crucible of mathematical principles for practical purposes. Technically, it can be defined as '*the application of scientific and mathematical principles to understand and*

[7] Summary of these views is found with Mark R. Riley (2007) in his "*Introducing Journal of Bioengineering*" at https://jbioleng.biomedcentral.com/articles/10.1186/1754-1611-1-1#CR5

[8] The word '*Bioengineering*' is comprised from the prefix '*bio*' which denotes things related to life, and '*engineering*' which stands for the application of mathematical principles to optimize nature for human needs, such as making designs, processes, and systems.

employ life systems for practical ends'. According to the National Institute of Health (NIH)[9], "Bioengineering integrates physical, chemical, mathematical sciences and engineering principles for the study of biology, medicine, behavior, or health"[10]. It advances fundamental concepts, creates knowledge for the molecular to the organ systems levels, and develops innovative biologics, materials, processes, implants, devices, and informatics approaches for the prevention, diagnosis, and treatment of disease, for patient rehabilitation, and for improving health" [5]. Encyclopedia Britannica defines 'bioengineering' as `the application of engineering knowledge to fields of medicine and biology'.

The above definitions are obviously focused on biomedical engineering, which is a central subject of bioengineering, but the broader meaning of biological engineering stretches beyond the medical area to address the full spectrum of the life sciences, including applications to agricultural, environmental, and ecological systems that utilize engineering approaches and rationale to deal with biological problems. The major application areas of bioengineering, according to Encyclopedia Britannica, include medical engineering, agriculture engineering, bionics, biochemical engineering, human factors engineering and bioenvironmental engineering.

Bioengineering, as an applied science, has become the major method to transform the knowledge of life science into practice. As elaborated by the Harvard University Bioengineering Plan, a large number of the basic mechanisms have been discovered and the essential mystery of life has been stripped away within the last few years in the history of molecular biology. For instance, biomedical engineering has yielded revolutionary advances, including new imaging modalities, prosthetic devices, dialysis, and drug delivery systems, and it is poised to tackle the increasingly complex and sophisticated problems of everyday life[11].

Indeed, the practical value of bioengineering in modern scientific platform has convinced professors of engineering to call for an integrated curriculum for engineering professions. They are suggesting that the three basic sciences that have been traditionally studied by engineering students, i.e. physics, chemistry, and mathematics, be integrated with biology. They stress that all engineers, regardless of their specializations, must be exposed in their undergraduate years to the biological sciences. Professor Johnson emphasizes that engineers of the future must be true synthesizers instead of just designers [15].

2.2.2 Biomedical Engineering

Using scientific principles to solve the practical problems of life is the key characteristic of bioengineering [23]. Biomedical engineering is the major application field of bioengineering; therefore, they are interchangeably used in many cases. Since technology has such a dramatic impact on medical care, engineering professionals have become intimately involved in many medical ventures. As a result, the discipline of biomedical engineering has emerged as an integrating medium for two dynamic professions, medicine and engineering, and has assisted in the struggle against illness and

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[9] See their website and following link: http://www.sci.utah.edu/~macleod/bioen/bme-definition.shtml

[10] Riley, Mark R. (2007) *Introducing Journal of Bioengineering*:

https://jbioleng.biomedcentral.com/articles/10.1186/1754-1611-1-1#CR5

[11] *Engineering Biology for the 21st Century A Plan for Bioengineering at Harvard* (https://hms.harvard.edu/sites/default/files/assets/About_Us/Off_Dean/files/Bioengineer.pdf)

disease by providing tools, such as biosensors, biomaterials, image processing, and artificial intelligence, that can be utilized for research, diagnosis, and treatment by health care professionals. Thus, biomedical engineers serve as relatively new members of the health care delivery team that seeks new solutions for the difficult problems confronting modern society [3].

There are various definitions for biomedical engineering. The Institute of Biological Engineering defines bioengineering as `the biology-based engineering discipline that integrates life sciences with engineering in the advancement and application of fundamental concepts of biological systems from molecular to ecosystem levels [5]. It also defined as 'application of the knowledge gained by a cross-fertilization of engineering and the biological sciences so that both will be fully utilized for the benefit of man' [22]. Others defined biomedical engineering as 'the application of engineering disciplines, technology, principles, and design concepts to medicine and biology' [9]. All these attempts emphasize that biomedical engineering integrates 'engineering' with 'medicine' and bridges the gap between them. As noted by Fazel-Reza, creating such a bridge requires deep understanding and major cross-disciplinary efforts by engineers, researchers, and physicians at health institutions, research centers, and industry sectors. The ultimate objective of all biomedical engineering fields, in research and education, is to improve the quality of life and reduce the impact of disease on individuals, and to provide an appropriate infrastructure to promote and enhance the interaction of biomedical engineering researchers. Generally, biomedical engineering includes several disciplines, such as bioinstrumentation, biostatistics, biotransformation, biomaterial, biomechanics, biosignal, biosystem, clinical, tissue, rehabilitation and cellular engineering [9].

The field of biomedical engineering, however, is ever expanding as new engineering applications in the medical field emerge. All fields of biomedical engineering science aim at creating an overall improvement in health care, in terms of diagnosis, treatment and prevention, through the application of physical science methodology [22]. Although the medical science has a long history, the technologically based health care system, however, has provided a wide range of capabilities for health care, such as effective diagnostic technologies and highly therapeutic methods for treatments.

3. THE PHILOSOPHICAL FOUNDATIONS OF MODERN BIOENGINEERING

The philosophical foundations of bioengineering are defined by its two components, *biology* and *engineering*, which imply the application of engineering methods to biological systems. Philosophy of biology, generally, deals with the theoretical questions of life science. This includes the theoretical problems of biology, in its traditional sense, and problems of the emerging approaches of biosciences such as systems biology (SB), evolutionary systems biology (ESB), and bioengineering. Philosophers of science believe that there are some distinctions between the natural laws that govern the physical processes and that which govern life systems. According Rudolf Carnap, physical laws are *mechanistic*, in the sense that they can be generalized by observation; while biological patterns are *theoretical*, in the sense that they may not be generalized by simple observations [4][12]. The method of physical sciences has been remarkably successful in developing approaches to understand and control the physical world. However, despite the

[12] We use the term 'theoretical' in the same sense of Rudolf Carnap's use as explained in the section of philosophy of physical sciences, bellow.

substantial efforts that have been made, the mechanistic approach of physical sciences seems to be unsuccessful at answering many critical questions of the life sciences. The study of the philosophical foundations of the emerging biosciences, such as SB, ESB, and bioengineering, is therefore essential to formulate their rational framework. This would enable to deal with the theoretical, ethical, and methodological problems of biosciences and to create new opportunities for understanding biological processes for practical purposes.

3.1 The Philosophy of Physical Sciences

The general philosophy of science investigates foundations, methods, and application of sciences. It is mainly concerned with the theoretical, ethical, and methodological questions of science that lead to perfection of scientific inquiry. This includes problems of scientific research method, clarification of concepts, classifications, reliability of theories, and the ultimate goal of scientific endeavor. Physical sciences are disciplines that are concerned with the study of inanimate natural objects including physics, chemistry, astronomy, and other related subjects [21]. Life science or biology is the counter part of the physical sciences. The method of bioengineering science tries to integrate biological and physical sciences through application of the method of physical sciences to deal with life sciences for practical purposes. In other words, bioengineering is the application of knowledge produced by the method of physical sciences on life sciences.

Philosophy of physical sciences is well investigated by the eminent figures of modern philosophy of science, such as Alfred North Whitehead (d.1947), Rudolf Caranp (d. 1970), C. D. Broad (d. 1971), and Karl R. Popper (d. 1994). Rudolf Carnap has made special focus on philosophy of physical sciences, through many of his renowned works, such as "*Introduction to Philosophy of Science*" and "*Philosophical Foundations of Physics*". With regard to understanding physical world, he identifies two modes of natural laws: the *empirical* laws, and the *theoretical* laws. Empirical laws, according to Carnap, are laws that can be confirmed directly by empirical observations[13]. They contain processes either directly observable by the senses or measurable by relatively simple techniques. Sometimes such laws are called empirical generalizations, as a reminder that they have been obtained by generalizing results found by observations and measurements (inductive method). They include not only simple *qualitative* laws, such as, "*All metal are good for electricity conduct*" but also *quantitative* laws that arise from simple measurements. The laws relating to pressure, volume, and temperature of gases are of this type [4].

The theoretical laws, according to Carnap, also called abstract or hypothetical laws, are laws that cannot be measured in simple and direct ways, such as laws that govern the behaviors of entities such as molecules, atoms, electrons, protons, electromagnetic fields, and others[14]. Carnap shifts the attention that a theoretical law is not to be distinguished from an empirical law by the fact that it is not well established, but by the fact that it contains terms of a different kind. The terms of a theoretical law do not refer to

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[13] Carnap shifts the attention here that philosophers and scientists have quite different ways of using the terms 'observable' and 'non-observable'. To a philosopher, 'observable' has a very narrow meaning. It applies to such properties as 'blue', 'hard', 'hot'. These are properties directly perceived by the senses. To the physicist, the word 'observable' has a much broader meaning; it includes any quantitative magnitude that can be measured in a relatively simple and direct way. For example, a philosopher would not consider a temperature of 80 degrees centigrade, or a weight of 93 pounds, as observable because there is no direct sensory perception of such magnitudes. To a physicist, both are observables because they can be measured in an extremely simple way. See: Rudolph Carnap (1966). *Philosophical Foundations of Physics.*

[14] As exampled by Carnap, I think these are the laws which are suitably applicable to study and understand the complex systems of biology.

observables even when the physicist's wide meaning for what can be observed is adopted. If there is a static field of large dimensions, which does not vary from point to point, physicists call it an observable field because it can be measured with a simple apparatus. But if the field changes from point to point in very small distances, or varies very quickly in time, perhaps changing billions of times each second, then it cannot be directly measured by simple techniques. Physicists would not call such a field observable [4]. Theoretical laws are concerned with non-observables of the physical world, and very often they are called micro or macro processes. Carnap uses the term ‘theoretical law’ in a wider sense to include all laws that contain non-observables, regardless of whether they are micro-concepts or macro-concepts [4].

3.2 Philosophy of Biology

The available literature on philosophy of science shows that modern philosophy is more focused on physical sciences. In other words, many fields of life science are still fresh for philosophical exploration. This might be due to the historical fact that the physical sciences were developed first, but it also emphasizes the fact that the philosophy of biology is increasingly shifting attention of philosophers of science.

3.2.1 The Subject Matter of Biological Philosophy

Philosophy of biology is generally concerned with methodological, theoretical, and ethical questions of life sciences. This includes the traditional questions of biology, such as the origin of life or the diversity and source of change in living creatures; beside the critical questions posted by the emerging branches of biotechnology and bioengineering, such as systems biology and evolutionary systems biology. Some authors suggest that philosophers of modern biology have been engaged with three major themes: *firstly*, they are arguing about the position of biology in relation to physical sciences: is it regarded as an autonomous science or not? *Secondly*, they are discussing evolutionary biology that studies how living systems came to be; and *finally,* philosophers of biology are arguing about biological functions and causal explanation [10].

Exceptional to the philosophical questions that are posed by the evolution theory in the nineteenth century, modern philosophy of science hardly explored the nature, method, and the functional issues of life sciences. Beside the traditional questions pertaining to evolution of living creatures, the modern philosophy of biology should focused on molecular and experimental biology. As observed by many authors, this philosophical trend is necessary largely due to the rise of genetics and molecular biology[15].

3.2.2 Biology of Being and Becoming

For the purposes of this article, the biological sciences can be divided, based on their method of explanation, into two basic parts: *first*, biology in its traditional sense that concerns with the study of living organisms to understand their morphology, physiology, and anatomy; and *second*, the newly emerging trends of bioscience, which aim at understanding the complex systems of life for practical purposes. This type is mainly concerned with particular forms of biological changes that seem to have a directional component or goal-guided functions. Understanding the directional change behavior of biological systems may lead to the prediction of their future. This is clearly informed by principles of modern genetic engineering.

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[15] Ingo Brigandt. *Philosophy of biology*. Draft of a contribution to The Continuum Companion to the Philosophy of Science, edited by Steven French and Juha Saatsi. Continuum Press, London. P 2

The major difference between the two modes of biology is that the first one is biology of being, in sense that we study systems to understand their constructions and functions; while the second is biology of becoming which aims to predict the future of biological systems based on understanding their behavior as governed by theoretical laws of nature [10]. In this article, we use the term *biosciences* to indicate the latter type, which includes new approaches, such as stems biology, evolution systems biology, and bioengineering.

3.3 Philosophy of Evolutionary Biology

The theory of biological evolution is central in modern biology. It is the philosophical foundation which provides the scientific explanation why there are so many different kinds of organisms on the planet earth, and gives an account of their similarities and differences. According to its proponents, evolution is the process that explains how today's organisms have descended from their ancient ancestors. It explains living creatures in terms of their morphological, physiological, and genetic development. This theory was developed profoundly, as a comprehensive philosophical approach to understand living organisms, by Charles Darwin in his eminent work "*On the Origin of Species*", in 1859. In this book Darwin answers the two fundamental questions on living organisms: (i) the question about the origin of life and the cause of change in living creatures; and (ii) the question about source of diversity and fascinating characteristics of living creatures. Both questions are philosophical in nature. Darwin, in this theory, emphasizes that the various forms of life on earth gradually evolved from the simplest kinds of organisms by means of natural selection. He further explains that the evolution and adaptations of organisms are the outcome of a process that causes, over time, the gradual accumulation of features beneficial to organisms, whenever these features increase the organisms' chances for survival and reproduction [6].

The basis of natural selection, according to this theory, lies in three facts: *first*, the characteristic of *heredity* which means that an individual organism plant or animal produces offspring after its own image. *Second,* the offspring does not completely run after the image of the parent, but may differ from it in ways also subject to heredity. *The third* element of Darwinian evolution is that the overreach pattern of spontaneous variation is trimmed by difference in the viability of different variation, most of which, tend to diminish the probability of continued racial existence, although some, perhaps very few, tend to increase it [25].

3.3.1 The Mechanism of Evolution and Change

Each of the following four processes is regarded as a mechanism of evolutionary change:

i. **Mutation:** the changing in the structure of a gene caused by the alteration in DNA, which results in variation in the subsequent generations. For example, it could cause parents with genes for bright green coloration to have offspring with a gene for brown coloration.

ii. **Migration:** movement of populations, groups or individuals from one region to another. In genetic, migration causes movement of genes from one population into another (gene flow).

iii. **Genetic drift**: change in type of genes in a population due to random reproduction, that leads a gene to get popular qualities or may lead to the total disappearance (sterilization). When an organism which has genes causing a specific genetic trait reproduced with another which does not have similar gene characteristics, the resulting genes may get better qualities or they totally disappear. It is variation in the relative frequency of genotypes, in a small population, that may lead to the disappearance of particular genes as individuals die or do not reproduce. For example, imagine that in one generation, two brown beetles happened to have four offspring that survived to reproduce. Several green beetles were killed when someone stepped on them and had no offspring. The next generation would have a few more brown beetles than the previous generation. These changes from generation to generation are known as genetic drift[6].

iv. **Natural selection:** the process through which the organisms will be adapted to their environment to get better chances for survival and reproduction. It is the process by which the organism with favorable traits enables them to adopt themselves to specific environmental pressure, such as climate changes or competition for food or mates, to survive and reproduce rather than others of their kind, thus ensuring the perpetuation of those favorable traits in succeeding generations. Charles Darwin believed that the natural selection is the main factor that brings about evolution[6][16].

The most controversial part of the theory of evolution is its basic assumption that the process of evolution and adaptation of organisms is purely internal (natural), without any involvement of external being or supernatural power.

3.3.2 Criticism of Evolution Theory

The evolution theory became controversial and created various conflicting views among biologists, as well as among the other intellectuals. The proponents of the theory emphasize that nothing in biology makes sense except in the light of evolutionv[8]. They further explain that the acceptance of evolution meant the world could no longer be considered merely as seat of activity of physical laws but had to incorporate history and, more importantly, the observed changes in the living world in the course of time [19].

The opponents of the theory, on the other hand, hold that despite the excellent capabilities of evolution theory to expose mankind to the understanding of living creatures, the major problem of the theory however lies in its basic assumption that proposes an explanation that removes the role of any external force in the evolution process. This assumption, as held by many intellectuals, does not answer many important questions about the perfect structural orders and systematic functions of living creatures. This account is known as '*design argument*', which has been held since the early history of religious thought by theologians to prove the existence of God (the Intelligent Mind) as sole creator and designer of life systems[17].

The common ground of the *evolutionists* and *creationists*, however, is that both agree that the evolution theory was a great leap towards the proper understanding of living organisms in the history of biological science. However, the evolution theory has nothing

[16] See a good presentation on evolution theory by Ernst Mayr (2002) in his eminent work "*What Evolution is*", published by Phoenix, London-UK, forward by Jared M. Diamond.

[17] Theologians are keen with the design argument to prove existence of God rationally. One of the earliest who emphasized this argument was Ibn Rush (d. 1198), in his book "*Faslul al-Maqal*", but the best who argued for this account was William Paley (1743-1805) who made a systemic presentation in his eminent work, entitled "*Natural Theology*" in which he aimed to prove God, not nature or chance, was the source of evolution, change, and diversity of living creatures. I think Paley's discourse in this book inspired, in one way or another, Darwin's account in the sense that it shifted his attention to the mechanistic approach instead of teleological explanation that was dominant.

to do with the question of the efficient cause of an organism, which has been the major concern of teleological approach. The evolution theory, as articulated by Darwin, constitutes the philosophical foundations of modern biology, but a biology which is *descriptive* rather than *predictive*, a biology that asserts that an understanding of the living world will come from descriptions of the history of organisms, in particular their genetic history, and from a catalogue of the molecules of which organisms are composed. This is what differentiates the philosophies of evolutionary biology and systems biology. The former studies how living systems came to be, whereas systems biology studies how living systems are or how it should be. It is the biology of being versus the biology of becoming, and this is the profound difference. The aim of systems biology is to understand how functional properties and behavior of living organisms are brought about by the interactions of their constituents [10].

3.4 Philosophy of Systems Biology

The emergence of systems biology as a new field has necessitated construction of its philosophical foundations. Systems biology, in fact, is regarded as one of the most promising and pragmatic approaches to life science. It needs, therefore, a considerable effort to develop its own philosophical foundations. The available literature is focused on fundamentals[18], principles[19], functions, and applications of systems biology[20]. There are only a few works to address the question of philosophy in systems biology. One of the most comprehensive works on this topic, among others, is "*Systems Biology Philosophical Foundations*", which edited by Fred C. Boogerd, Frank J. Bruggeman, Jan-Hendrik S. Hofmeyr, and Hans V. Westerhoff (First edition 2007) [21]. The authors of the book believe that systems biology is the culmination of biology. In the first section under title: *Towards Philosophical foundations of Systems Biology*, the authors explain that the aim of systems biology. It is to understand how functional properties and behavior of living organisms are brought about by the interactions of their constituents. They emphasize that the contemporary systems biology is a vigorous and expanding discipline, in many ways a successor to molecular biology and genomics on the one hand and mathematical biology and biophysics on the other.

The interdisciplinary nature of systems biology was also emphasized by the authors: "It is perhaps unprecedented in its combination of biology with a great many other sciences, from physics to ecology, mathematics to medicine and linguistics to chemistry" [10]. The major difference between molecular biology and systems biology was clearly identified by the authors. They hold that the aim of molecular biology is to characterize the molecular constituents of living organisms. It measures the properties of each component and, in the case of molecular cell biology, its localization in the living cell. Although its methods and results are breathtaking and highly important, they are straightforward and do not require any philosophy that extends the philosophical foundations of physics. By contrast, systems biology is concerned with the relationship

[18] See for example: *Foundations of Systems Biology* / edited by Hiroaki Kitano (2001) and also: *What is Stems Biology*? / by Rainer Breitling (2010)

[19] See for example: *Tracing organizing principles: Learning from the history of systems biology* / by Sara Green and Olaf Wolkenhauer.

[20] One of the useful works in application of systems biology is a book entitled "Understanding and Exploiting Systems Biology in Biomedicine and Bioprocesses" edited by Manuel Canovas, Jose L. Iborra, and Aruro Manjon (2006). The major themes of the book are: systems biology, fundamentals and tools systems biology applications, biomedicine, systems biology applications, and bioprocesses.

[21] Beside others, I think, Fred C. Boogerd and his colleagues, Maureen A. O'Malley and Sara Green (who earned her PhD in this field), have done their best to develop and promote the philosophy of this newly emerging science.

between molecules and cells. It is concerned with how the functional properties in the molecules emerge from the particular organization of and interactions between its molecular processes. Systems biology uses models to describe particular cells and generalizes over various cell types and organisms to arrive at new theories of cells as molecular systems [10].

The importance of philosophical foundations of systems biology was highlighted by the authors as well, emphasizing that "because systems biology may well become main stream biology and medicine in the coming years, and because practicing systems biologists are often hindered by paradigm battles with molecular biologists, we found it important that this issue be discussed intensely and openly by experts in fields ranging from molecular and systems biology to the philosophy of science" [10].

The book was reviewed by Jonathan F. Davies and Maureen A. O'Malley, who credited the book by the following words: "*Systems Biology: Philosophical Foundations*' is an insightful and timely book that fuses scientific and philosophical insights in a highly effective and mostly accessible manner. Numerous books address scientific aspects of the emerging and expansive field of systems biology but this is the first to deal specifically with its underlying philosophical issues. A key aim of this book is to bring the philosophy of biology into a new mode of biological thinking and expand the limited range of biological research it has tended to address. This is an aim very likely to be realized as systems biology becomes increasingly a topic of reflection for philosophers of biology" [7].

4. THE ETHICAL CONCERNS OF BIOENGINEERING

The pragmatic nature of bioengineering science may qualify it to be the science of the new millennium, especially in relation to the enhancement of human health and preservation of environment ecosystems. To harness potentials of bioengineering, however, the ethical concerns must be observed. In fact, there are critical ethico-legal questions posed by advanced bioengineering research and its applications, especially in biomedical engineering. Beside the classical ethical problems, the modern biomedical engineering has produced more serious ethical questions across its various stages, in research as well as application.

The ethical issues of bioengineering are currently studied in various fields, such as bioethics, biomedical ethics and engineering ethics. From a holistic perspective, however, the basic structure of ethical enterprise can be divided, for the purpose of this article, into three major groups: (i) issues of clinical ethics, (ii) research ethics, and (iii) bioethics. Clinical research ethics is mainly concerned with ethical matters related to living organisms used for medical research purposes, especially human elements. This could be extended to all medical professions and practices. Therefore, clinical ethics requires both personal ethics, such as honesty and sincerity, as well as protocols which assigned strictly by the medical professions, which must be observed regardless of personal religious background. Such protocols are necessary to guarantee the objective of good medical practices. Research ethics are related to personal ethics, which is essential for proper knowledge production and scientific progress. Research ethics is mainly concerned with three basic types of deviation in proper research conduct: fabrication, falsification, and plagiarism (FFP), besides other types which belong to none of these three.

"Bioethics" is the major concern of bioengineering philosophy, due to its critical consequences on life, human health and environment. The term "bioethics" is used for all ethical concerns related to the new technologies of life sciences (bioengineering), either in medical field, such as genetic and tissue engineering (biomedical ethics), or related to biotechnology as general, such as genetic modification and cloning. Issues of biomedical ethics can be divided into two basic types: (i) classical issues, such as organ transplantation, abortion, and euthanasia; and (ii) issues of advanced bioengineering technology, such as stem cell, genetic modification, reproduction technology, biomedical imaging, and neural engineering [2].

4.1 Ethics of the Advanced Bioengineering

Ethics of advanced bioengineering includes all forms of advanced biotechnology research and practices, such as genetic modification, tissue engineering, biomaterials and prostheses, and ethics of biomedical imaging. In fact the scientific progress in both fields of physical and biological sciences has posed complicated ethical problems. Therefore, '*ethics*' has become a common theme for various fields of scientific research. The eminent mathematician Norbert Wiener, the father of '*Cybernetics*' whose theories assisted in producing the goal-guided missiles during the World War II, has expressed his deep concern about the social and ethical implications of scientific progress. He especially emphasizes the importance of observing the ethical concerns in advanced technologies. In his eminent work "*God and Golem*" Wiener observes that: "Knowledge is inextricably intertwined with communication, power with control, and the evaluation of human purposes ethics and the whole normative side of religion". Wiener emphasizes in his book "*The Human Use of the Human Being*, 1989", that (We are swimming upstream against a great torrent of disorganization, which tends to reduce everything to the heat death of equilibrium and sameness described in the second law of thermodynamics). He further explains (What Maxwell, Bolzmann and Gibbs meant by this heat death in physics has a counterpart in the ethics of Kierkegaard, who pointed out that we live in a chaotic moral universe). In his discussion of ethical concerns on modern technology, Wiener observes consequences of advanced technologies on environmental ecology, human health, and social life. Through integration of advanced technologies with moral values, Wiener was attempting to articulate foundations of a meaningful life. For that purpose, his eminent works "*The Human Use of Human Being*" and "*God and Golem*" were produced, where he discussed ethical issues at length.

4.2 Ethics of Bioengineering from an Islamic Perspective

For proper development of human life, man needs two elements: *first*, natural resources to maintain life and to fulfill the material needs of an individual and society, and *second*, knowledge of the principles of individual and social behavior to fulfill himself and to maintain justice and tranquility in human life. The latter type constitutes foundations of law, ethics and moral values. Islam, as a final mode of Divine revelation, has addressed and provided both of these elements in full measure[22]. The Islamic code of ethics, therefore, is capable of managing all human affairs, in everyday life, in social interactions, scientific research, as well as in personal affairs. With regard to scientific research and application, there is no specific code of ethics for this sort of human activity but there are general principles to guide the steps. These principles were compiled and summarized by early Muslim scholars in five major objectives of Islamic law, known as *Maqasid al-Shariah*, which consisted of: (i) preservation of religious freedom, (ii) preservation of human life, (iii) preservation of mind, (iv) preservation of human progeny, and (v)

[22] With few modifications, the statement was adopted from a revised version of an article Written by Khurshid Ahmad, entitled "*Islam: Basic Principles and Characteristics*", published by Islamic Publications Ltd., Lahore.

preservation of property. The contemporary Muslim scholars regarded preservation of nature as the sixth objective.

The entire philosophy of the Islamic legal system aims at promoting these principles and protecting human interests (*Maslah*). Beside commandments of God, these principles provide all the necessary guidelines to determine what is permissible and what is impermissible (*halal* and *haram*) in Islam. For example, the principle of preservation of human life aims to promote human dignity and to maintain a meaningful life, therefore it forbids all acts and activities which expose human dignity for humiliation or cause death, such as using human subjects for research purposes without free and informed consent. Moreover, the principle of progeny preservation aims to sustain human reproduction, based on principle of human dignity. Accordingly, it will consider some reproduction methods of modern bioengineering as impermissible. For instance, by application of the above two principles, it can be decided that reproduction of what is named as "*motherless-babies*" or "*fatherless-babies*" is impermissible in Islam [1].

There are enormous works and countless religious rulings (*fatwa*) issued within the last few decades to deal with the major ethical problems of advanced bioengineering technology. In many cases there was inconsistency between the various rulings on the same issue. Lack of standard criterion for judgment might be the major source of diversity among Muslim scholars' views on many issues of bioengineering ethics. The rigid observation of above principles of Islamic law "*Maqasid al-Shariah*", therefore, would provide an objective standard of judgment for various forms of human activities, especially in bioengineering technology.

5. CONCLUSION

According to the traditional philosophy of science, natural processes, i.e. physical and chemical, are understood based on causal explanation. Meanwhile the biological (goal-guided) processes and conscious acts of human being are understood based on teleological explanation. The major difference between the two methods lies in the relationship between the cause and effect. In biological processes, the future determines the present, while in physical processes the past determines the future. However, the distinction between physical and biological processes, according to the integrated approach, is unnecessary. Theories, such as goal-directed control or information feedback control, are developed by the 'Cybernetics' research method to emphasize the integrated approach.

Indeed, the new integrated method of scientific inquiry has made remarkable implications on both physical and biological sciences. One of the major impacts on biological research was the tremendous progress in bioengineering science within the last few decades. The advancement in bioengineering has brought the *science of biology*, in classical sense, to its turning point. Biology now is ready only to deal with the method of physical sciences, creating firm engagement with mathematics, engineering and computer sciences, to serve the practical needs of mankind on earth. This new approach in biological research clearly emphasizes the quantitative method that enables scientists to predict biological processes, leading to new means to control them. To harness potentials of modern bioengineering, it is necessary to acquire both the practical and theoretical knowledge of bioengineering. As emphasized by Prof. Johnson, bioengineers should have the conceptual and philosophical framework of biological science which is essential for fundamentals of bioengineering. This entails that the ideal bioengineers should be capable of incorporating the ethical, aesthetic, and environmental aspects into the processes and products. They should also be capable of thinking analogically and comprehensively, in the sense that they will be able to transfer knowledge from a system that is familiar to that unfamiliar. Generally, the study of the philosophy of science initiates the interdisciplinary approach, provides deep insights, develops analytical skills, and opens new horizons for scientific research. For actualization of such a motivating proposal, the authors of this article emphasize the following three requirements: *first*, engineering students, regardless of their area of specialization, should be exposed to the biological sciences, especially to the systems biology approach. *Second*, all science and engineering students should be aware of the philosophical foundations of modern science. This point may need to be emphasized by offering courses on the philosophy of science as core subjects to all. *Third*, bioengineering research must be integrated with ethics and moral values to produce green technologies that are free from any potential harm to the environment or to human health.

ACKNOWLEDGEMENT

Authors of this article acknowledge all cited works and their authors for valuable thoughts benefited; especially those whose texts and conclusions were directly cited. We especially acknowledge Norbert Wiener, Sawhney, G.S., and Arthur T. Johnson who inspired the basic idea of the paper. We acknowledge Rudolf Coranp who benefited this work by his classifications on method of physical sciences. The authors also acknowledge Klipp, E. et al. and Joel L. Cuello; Fred C. Boogerd, et al., Frederick B. Marcus, and others for insights benefited from their remarkable works. Our thanks are due to everybody who contributed in the production of this work and those who have provided assistance in making it a reality.

Fred C. Boogerd, Frank J. Bruggeman, Jan-Hendrik S. Hofmeyr, and Hans V. Westerhoff, eds Amsterdam: Elsevier, 2007

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