

## Life as Basic Science and its Impact on Medicine

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### Abstract:

This chapter discusses the profound implications of studying life as a basic science and its intersection with the practice of medicine. It begins by defining key terms such as "life," "basic science," and "medicine." Throughout history, the pursuit of basic science has influenced medical practices, from ancient cultures to the modern era. The text traces the evolution of basic science in medicine, highlighting key developments such as cell theory and molecular biology. Cell theory revolutionized medical understanding by providing insights into pathological processes and enabling targeted treatments. Similarly, advancements in molecular biology, including the discovery of DNA structure and the completion of the Human Genome Project, have paved the way for personalized medicine. Challenges and future directions in personalized medicine, including ethical considerations and technological advancements such as single-cell omics and artificial intelligence, are also explored. The chapter concludes by emphasizing the potential of personalized medicine to revolutionize healthcare through tailored treatments and individualized care.

### Introduction:

What does it truly mean to study life as a basic science? And what impact does such a study have on the practice of medicine? Before we address the above two questions, it is important to define the three key terms under consideration, namely, "life", "basic science", and "medicine". Life (*verb form: to be living*) can be broadly defined as the ability of a given unit of matter to recognize itself as a "self", to use energy from the earth's environment to grow and to reproduce its "self", to mount a response to any stimulus received by its "self"; and as such, any unit of matter that possesses all of these abilities is said to be living. Basic science is defined as the use of scientific inquiry and research methodologies to provide a fundamental understanding of the natural world. Medicine can be defined as the practice concerned with the maintenance of human health and the prevention, alleviation, or cure of disease (Encyclopedia Britannica, 2023). Basic science delves into the fundamental questions of how life works, aiming to unravel the intricate mechanisms governing biological phenomena. By comprehending the intricacies of life at its most elemental level, researchers can pave the way for advancements in predicting, preventing, diagnosing, and treating diseases. Basic science aimed at understanding life thus forms the foundation upon which medical breakthroughs are made.

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## The Intersection of Basic Science and Medicine - Ancient Times to the Middle Ages

Evidence of the pursuit of basic science and its influence on the practice of medicine can be traced as far back as around 3000 to 1200 BCE. (Lindberg 2007). For example, careful observation and study led to the discovery of antibiotic properties in naturally occurring substances such as honey and onions. (Metwaly et al. 2021).

Ayurveda, a natural system of medicine, is thought to have originated in India more than 3,000 years ago. One among the four Vedas of ancient India, the Atharvaveda has a detailed description of how to specifically wrap open wounds with Indus valley region plants. In several ancient cultures across the world, the understanding of astronomy as a basic science, was considered important enough to affect medical practice and healing rituals. For over 2000 years, medicinal healers in China and large portions of Asia are also documented to have used various herbal powders, dust made from various animal parts, and strategically placed needles to treat human ailments, although there is less known documentation of the intersection of these empirically obtained treatment approaches and their intersection with the basic sciences.

Ancient Greek medicine mainly revolved around the theory stating that good health comes from a perfect balance of the four humors: blood, phlegm, yellow bile, and black bile, and poor health was understood to be a result of improper balance of the four humors. The theory of humors had a great impact on medicine throughout the Middle Ages and extended into the Renaissance and even the Early Modern period. Some of the most important developments in medicine between the seventh and the eleventh centuries took place in the Middle East, and connections between basic science and medicine are evident. For example, the famous book called *Collection of Simple Drugs and Food*, is an alphabetically arranged compendium of medicinal plants, along with information about drug preparation, administration, and dosage. Meanwhile, the practice of medicine in Mesoamerican cultures can be traced back to the year 1500 BC. The classic codex, which was written in 1552, contains descriptions of plant-based remedies for several ailments including boils, hair loss, joint diseases, and tumors, among others. Thus, from ancient times and throughout the Middle Ages, all around the world, the careful observation, study, and documentation of newly discovered natural phenomena went hand-in-hand with the application of those discoveries towards aims considered useful for purposes of human healing.

## Theory of the Cell as Basic Science, and its Impact on Modern Medicine

The basic science understanding of life's fundamental unit, the living cell, is expounded in cell theory. Proposed in the early 19th century, cell theory revolutionized scientific thought, paving the way for significant advancements in medicine ranging from antibiotics to modern-day cell-based therapies for treating cancer.

Cell theory provided a framework for understanding pathological processes, such as infections, genetic disorders, and cancer. Through microscopic examination, clinicians could identify abnormalities within cells, leading to more accurate diagnoses and targeted treatments. For example, the discovery of bacteria as the causative agents of infectious diseases, such as

tuberculosis and cholera, revolutionized public health practices, paving the way for antibiotics and vaccination.

In more recent times, techniques such as tissue culture and stem cell generation and maintenance have opened new avenues for regenerative medicine and personalized therapies. By harnessing the potential of cells, scientists can now engineer tissues and organs for transplantation, regenerate damaged tissues, and develop targeted therapies for various diseases.

### **Impact of Basic Molecular Biology on the Practice of Medicine**

Advancements in chemistry and biology in the 20<sup>th</sup> century resulted in the elucidation of molecular structures, particularly DNA, RNA, and proteins, which provided a molecular basis for understanding the mechanisms of life. Biochemistry emerged as a distinct discipline, bridging the gap between chemistry and biology.

One of the most significant milestones in understanding life at the molecular level was the discovery of the structure of DNA by James Watson, Rosalind Franklin, and Francis Crick in 1953. This groundbreaking achievement revealed the molecular basis of heredity and laid the foundation for the field of molecular genetics. Subsequent research led to the deciphering of the genetic code, the sequence of nucleotides that dictates the synthesis of proteins.

Molecular biology emerged as a multidisciplinary field focused on uncovering the molecular mechanisms that drive complex biological processes. Techniques such as recombinant DNA technology, polymerase chain reaction (PCR), and genome sequencing revolutionized biological research, enabling scientists to manipulate and study molecules with unprecedented precision.

The completion of the Human Genome Project in 2003 marked a monumental achievement in the field of genomics, laying the foundation for personalized medicine. This ambitious endeavor deciphered the entire human genetic code, providing insights into the genetic underpinnings of health and disease. Armed with this knowledge, researchers and clinicians embarked on a quest to unravel the complexities of the genome and harness its potential for personalized healthcare.

In recent decades, advances in genomics and proteomics have further expanded our understanding of life at the molecular level. The sequencing of the human genome and the genomes of other organisms has provided invaluable insights into the genetic basis of health and disease. Transcriptomics, the study of patterns in RNA expression and their functional significance in cells, has paved the way for novel mechanistic insights. Meanwhile epigenomics, which is the study of how genes are switched on and off without changing the actual DNA sequence, has fine-tuned the insights gained from epigenomics. Proteomics, the study of proteins on a global scale, has uncovered the complex networks of interactions that govern cellular function. Metabolomics is the study of the small molecules that are products of energy generating and utilizing reactions occurring throughout the human body within each cell and is poised to revolutionize the discovery of novel diagnostic biomarkers. Overall, systems biology approaches are emerging to study life as a composition of integrated systems, thus considering the interactions between genes, proteins, and other molecules in living organisms, and giving rise to the era of personalized medicine.

## Challenges and Future Directions:

Personalized medicine has immense potential, but also brings forth new challenges, including ethical considerations and disparities in access. The integration of genomic information into clinical practice requires infrastructure, collaboration, and evidence-based guidelines to ensure safe and effective implementation.

In recent times, the exploration of personalized approaches to diagnosis and treatment has been steadily advancing, driven by technological innovations and a deeper understanding of biological systems. With the advent of newer technologies such as single-cell RNA sequencing and proteomics, the profound complexity and heterogeneity of living systems can finally be studied at multiple levels of biological organization. However, effectively implementing these cutting-edge technologies is still challenging for multiple reasons.

One challenge lies in the integration of multi-omics data streams, including transcriptomic, proteomic, and metabolomic data, to generate a comprehensive understanding of cellular function. The translation of single-cell omics findings into clinically actionable insights is important. Close collaboration between researchers, clinicians, and industry partners is necessary for validating findings, developing robust, reproducible analytical pipelines, and navigating novel regulatory considerations.

Integrating single-cell omics technologies with advanced computational and artificial intelligence (AI) methodologies is the way of the future. Using AI-based analytical models, researchers can uncover novel hidden patterns and relationships in integrated multi-omics datasets, and these patterns and relationships may hold the key to effective medical treatment strategies. Furthermore, advances in single-cell imaging and spatial profiling techniques enable the visualization of cellular interactions and microenvironmental dynamics in a detailed manner, thus further enhancing our understanding of disease processes.

In conclusion, by harnessing the power of predictive and generative AI to integrate multi-omics data generated by multiple novel complementary technologies, researchers are poised to unlock new frontiers in cellular biology and pave the way for more precise and effective treatments tailored to individual patients. However, realizing this vision will require concerted efforts to address technical limitations, integrate multi-omics data streams, and translate research findings into clinical practice. With perseverance and innovation, personalized medicine promises to revolutionize healthcare, ushering in an era of truly individualized care tailored to the unique needs of each patient.

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