Biology for Engineers

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Features of

LEARNING OUTCOMES

After studying the material in this chapter, readers will be able to:

1. Define a lipid and give reasons for the status of lipid as a fundamental biomolecule
2. Draw a schematic of the Singer and Nicolson view of the cell membrane
3. Provide a mental picture of the packed intracellular space
4. Relate the structure of a lipid to the properties of a cell membrane which is composed of those lipids
5. Relate the structure of the cell membrane to its functions

Learning Outcomes This feature helps the readers get a brief idea about the topics that will be discussed in a chapter.

Figures and Tables The text is supported with figures and tables for better understanding of concepts.

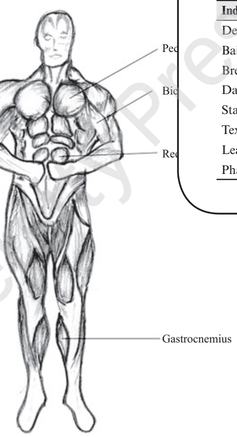

Figure 11.9 A schematic of the human muscular system with some popular muscles named

Table 5.2 Common enzymes used in various industries

Industry	Enzymes used
Detergent	Proteases, Amylases
Baking	Amylases
Brewing	Amylases, Glucanases, Proteases
Dairy	Rennin, Lipases, Lactases
Starch	Amylases, Glucose isomerase
Textile	Amylase
Leather	Trypsin, Proteases, Cocktails
Pharmaceuticals	Trypsin

REFLECTION POINT 7.2

2. Why is a RNA primer needed for DNA replication? Can't DNA nucleotides be directly added?
3. Why does the new DNA chain elongate only in the 5′ to 3′ direction, and not 3′ to 5′?
4. In question 3, what does the prime (′) refer to?

Reflection Points This feature reflects upon the topics being discussed in a chapter. These encourage application of mind and active learning either alone, or in groups in class.

Additional Information For readers who are interested in deeper reading, the book comes with additional information at the end of each chapter.

ADDITIONAL INFORMATION

1. If interested in the development of the gene to protein idea when the molecular nature of the genes were yet to be identified, read Archibald Garrod's work on 'genes' being responsible to metabolic disorders in 1909. One can begin by reading the information in a standard Biology textbook. For example, see the relevant section in the chapter titled, 'From Gene to Protein' in Campbell Biology, 11th edition, Benjamin-Cummins, 2018.

the Book

Summative Assessment Multiple-choice questions are included in each chapter for testing the knowledge of readers.

SUMMATIVE ASSESSMENT

MULTIPLE-CHOICE QUESTIONS

1. Choose the correct match(es) among the following:
   (a) Cystic fibrosis–improper function of the chloride channel
   (b) Down's Syndrome–deletion in chromosome 21
   (c) G6PD deficiency–deficiency of glucose-6-phosphatase enzyme
   (d) All the above
2. Which of the following statements are true?
   (a) A character has many traits
   (b) A trait has many characters
   (c) The allele idea is the same as the gene idea
   (d) In Mendelian genetics, four alleles determine the expression of a phenotype in an individual.

POINTS TO REMEMBER

1. Cell is the fundamental functional unit of life.
2. Broadly, there are two types of cells—prokaryotes that came before the nucleus and thus they do not have a well-defined nucleus, and eukaryotes that have a well-defined nucleus.
3. The properties of life include organization, metabolism, homeostasis, growth, reproduction, response, and adaptation.

GLOSSARY

3-D printing: Printing whole objects in three dimensions with an appropriate machine called a 3-D printer.
5' cap: The molecule attached to the 5' terminus of a pre-mRNA.
α-helix: A secondary structure of a protein.
β-sheet: A secondary structure of a protein.

A site: One of the three t-RNA binding sites in a ribosome during translation. The tRNA carrying the amino acid first binds to the A site.
Abdominal cavity: The body cavity that houses the organs of the digestive, excretory, and reproductive systems say, in humans.

Summary and Glossary For quick recapitulation of concepts, each chapter contains the Points to Remember section. Glossary of key terms is added at the end for additional details on certain terms used in the book.

Appendices Appendices A-J provide information on certain topics for detailed understanding.

APPENDIX A
LABORATORY STERILIZATION

Large spaces such as laboratories can be sterilized by using vapours of suitable sterilizing agents that kill microorganisms. The sterilization process needs to be done carefully, with no inappro-

APPENDIX B
BIO-SAFETY LEVELS

When working with microorganisms, we need to be aware of the danger posed by them, and we need to take the necessary steps to avoid exposure to pathogens. To facilitate and streamline

APPENDIX C
GRAM STAINING

Gram staining is an important method of classifying bacteria. It was developed by Hans Christian Gram, a Dutch scientist, in 1884. The basis for the test is the difference in the cell wall composition of bacteria.
The procedure is as follows:
(a) Treat bacterial cells with crystal violet dye. All bacteria will take up the dye to stain and appear violet under a light microscope. Iodine is used as a mordant to strengthen the ability of the cells to retain the crystal violet dye (fixing the dye). The iodine-crystal violet complex

PREFACE

In the past few centuries, many ground-breaking technologies and products were developed through a better understanding of physics and chemistry. In this century, often called 'the century of biology' in the context of advancements and contributions, a better understanding of biology is expected to lead to revolutionary technologies and products. Many engineers are expected to contribute to biological aspects to fuel this revolution. Unfortunately, an overwhelming majority of engineers are not comfortable with biology.

RATIONALE FOR THE BOOK

Students who take up undergraduate engineering studies in our country can be categorised into two groups—students who have taken biology after 10^{th} standard and students who have not. Some of the students who have taken biology after 10^{th} standard and have done well may already have the motivation and skills to effectively learn biology, whereas others in this group as well as many in the group without biology may not. The data collected over the past 10+ years, say that about 98 per cent of the IIT Madras engineering undergraduates who have not taken biology after 10^{th} standard, hate biology. The hate seems to be due to their earlier, uninspiring exposures to biology.

ABOUT THE BOOK

This book has a special purpose—to introduce biology to engineering students and other engineers who are not normally fond of biology. *Thus, it does not intend to be yet another traditional biology textbook.* The overall aim of this book is to provide suitable exposure to the fundamentals in biology in a manner that interests the engineering students, so that they would not be scared of biology and would be encouraged to refresh/update their knowledge to apply it effectively when needed later in life.

The engineering students have been trained to be highly focused and to quickly get to the most relevant point with as few words as possible, with a mathematical precision, if possible. This book attempts to do a similar thing in biology. *Most importantly, it emphasizes learning over mere information presentation.* It 'cuts to the chase' after the context is established and presents concepts in a way that eschews verbosity. However, there are ample directions to lead the student to additional information and various figures.

Further, the students who have a natural orientation to biology or those who have taken biology after 10^{th} standard will significantly benefit from the sections on 'Additional Information' included at the end of each chapter. In other words, the essential and basic concepts have been separated from the advanced concepts that arise from more details and depth in the same aspect, to better serve the needs of the wide engineering student population.

The author of this book realises the important role that biology plays in making good engineering contributions. Thus, it starts at the place where engineering students feel comfortable and gets them to see the most relevant aspects of biology, in a way that is not loathsome to them. For example, it does not merely list or describe biological terms or metabolic pathway reactions with an expectation that the students will make it a part of themselves by repeated study, as biology textbooks normally do. Instead, it introduces basic biological concepts in engineering or related contexts, gets the students to learn biology in their comfort zone (Chapters 2 to 6), and then slowly transitions them to the traditional way in which biological information is usually available.

Further, given the author's interest in the learning process, the book is based on strong, evidence-based pedagogical aspects, which would ensure learning, even if the text is read like a story and the reflection points are given due importance.

PEDAGOGICAL ASPECTS

In this book, the aspects discussed above are incorporated into sound pedagogic methods for a pleasant, but effective learning by students. Three major domains address the pedagogy: (1) learning dialogue (2) learning by doing, and (3) learning extensions.

The learning dialogue in the earlier part of the book, all the way until Chapter 6, is mainly through interesting stories, followed by focus on important principles at appropriate places. The important principles are strengthened at the various reflection points that are strategically placed at various parts of the chapter, sometimes after every sub-section. Most importantly, the mere listing of biological terms, biochemical reaction sequences, etc., that engineering students hated in high school, are avoided; instead the needed information is presented in appropriate application contexts. From Chapters 7 to 9, there is a gradual transition to a presentation closer to that found in the traditional texts to get the students slowly used to the way biological information is usually available. Chapters 10 and 11 are specially tailored for an engineering student—they give a bird's eye view of the use of Mendelian genetics principles and the coordinated action of various cell/tissue types in the context of human physiology.

The reflection points also incorporate elements of the second major pedagogic domain— learning by doing. The elements are working out small estimates, searching the web for needed info toward formative assessment, etc. These can also be done in groups in a class.

The third pedagogic domain, learning extensions, is addressed through material in the additional information section at the end of the chapter, by directing the reader to core biology textbook portions, journal publications, links to reputed websites, etc.

In addition, there are questions provided at the end of each chapter that can be used for summative assessment of student learning.

SALIENT FEATURES

The salient features of the book include:

- A tailor-made approach for the engineering students to easily learn biology
- A story-like presentation of biological concepts for easy understanding, which cuts across artificial, silo-like barriers that hamper effective learning for appropriate and effective use in the future.
- A clear presentation of biological concepts for effective learning.
- Strategically placed 'Reflection points' that encourage application of mind and *active learning* either alone, or in groups in class.
- 'Additional Information' at the end of each chapter to lead the interested reader toward deeper and wider learning.
- Carefully crafted 'Summative Assessment' section that provides questions to test different levels of learning.
- Comes with a 'Glossary of key terms' with explanation.
- 'Appendices' discussing topics, such as Gram Staining, Glycolysis, Derivation of the Michaelis-Menten equation, and Genetic Modification

- A presentation that is suitable to easily learn biological principles even for practising engineers or for anyone interested.
- Includes 'Points to Remember' at the end of each chapter for quick recapitulation of concepts.

CONTENT AND COVERAGE

The book is divided into 11 chapters and 10 appendices. Please see above for a detailed description of the special features of the book. Content-wise,

Chapter 1 establishes the need for engineers to know biology, and that engineers need not be afraid to look at biology. It also provides a lot of popular bio-based applications that the readers may have come across in the past.

Chapter 2 establishes the cell as the fundamental functional unit of life. It also discusses the origin of life on earth and the basic principles of evolution.

Chapters 3 to 6 present in engineering contexts, the fundamental biomolecules, and their roles in various cellular functions for easy learning of the absolute essentials in biology.

Chapters 7 and 8 discuss DNA replication and Cell replication, respectively, along with the cell cycle. The style of presentation introduces the traditional approach to biology in the background, but keeps a balance with the approach with which the engineering students feel comfortable.

Chapter 9 discusses Transcription and Translation, and the approach is close to the traditional one to prepare engineering students to further read biology texts with comfort.

Chapter 10 looks at the application of Mendelian principles.

Chapter 11 considers the coordinated function of cells and tissues in the context of human physiology.

Appendices A-J cover the following topics—laboratory sterilization, bio-safety levels, gram staining, some cell organelles, glycolysis, derivation of the Michaelis-Menten equation, TCA cycle, photosynthesis and Calvin cycle, typical media compositions for bacteria and mammalian cells, and genetic modification.

Glossary of key terms with explanation is provided at the end of the book.

DISCLAIMER

In this book, many videos that are available in the public domain have been recommended. They are recommended for their didactic value. The author and the publisher do not endorse the products in the videos.

ONLINE RESOURCES

To help teachers and students, the book is accompanied with the following online resources:

For Faculty:

- PPTs
- Chapter-end additional information links for quicker access

For Students:

- Chapter-end additional information links for quicker access

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G. K. Suraishkumar

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CHAPTER 1

WHY SHOULD ENGINEERS KNOW BIOLOGY?

LEARNING OUTCOMES

After studying the material in this chapter, readers will be able to:

1. Appreciate and list the reasons for an engineer to know biology
2. Appreciate and demonstrate that the learning principles are the same for biology and mathematics, or for that matter, any subject
3. Be mentally prepared to learn biological principles presented in the later chapters

INTRODUCTION

There are a number of options for undergraduate study in our country that nowadays seem acceptable to the society and are considered worthy enough to pursue. This is a healthy situation and the social acceptance of many undergraduate study options needs to improve further. Not so long ago in our country, there were only two socially preferred undergraduate streams for study—engineering and medicine. The usual groups (streams) for study at the higher secondary school level that led to the above preferred undergraduate streams were either mathematics—physics—chemistry—biology, mathematics—physics—chemistry—computer science, or physics—chemistry—biology. For engineering, mathematics is required and biology is not. Hence, only the first two groups are suitable for pursuit of an engineering degree. The relevant groups at the higher secondary school level that lead to undergraduate study in engineering or medicine have not changed much until now. Therefore, the students who enter engineering undergraduate studies may or may not have studied biology after their 10^{th} standard.

Another aspect is the innate interest of the student in biology. Irrespective of the group they choose to pursue at the higher secondary level, some students have an innate interest in biology, whereas others do not. The students who do not have an interest in biology or are neutral, when exposed to uninspired teaching of biology as a part of science at the high school (sixth to 10^{th} standard), most likely develop a hatred toward it. The frequency of occurrence of inspired, good teachers is low in any population, and thus, the above probably leads to a large number of high school students to hate biology. In some undergraduate engineering institutions in the country, a significant majority of students have not studied biology at the higher secondary level. For example, class surveys done at IIT Madras among all undergraduates who take the author's introductory course on Life Sciences or another related course show that usually, more than 90 per cent of the engineering undergraduates have not studied biology at the higher secondary stage. Among them, a disturbingly large majority (> 98%) hate biology.

Next in this chapter, we will establish the need for engineers to know biology. We will discuss many relevant examples. Then, we will show that in principle, there is no difference between learning mathematics and learning biology.

1.1 NEED FOR BIOLOGY

The previous few centuries saw a better fundamental understanding of the physical and chemical world through advances in physics and chemistry. The better understanding and advances gave rise to technologies and products, such as computers, communication devices, aircraft, and others that revolutionized life. Since this is the century of biology, a similar phenomenon is expected, which will lead to probably another revolution. Many engineers are expected to contribute to a biological aspect to fuel this revolution. Therefore, the engineering undergraduates need to be suitably exposed atleast to the very minimum biology, so that they would atleast be able to consider a biological system/aspect in which they could later make appropriate contributions, through their main expertise, say electrical engineering, mechanical engineering, computer science, materials engineering, or any other. Let us elaborate further in the following sections.

1.1.1 Shinkansen Sonic Boom

Many man-made things have significant scope for optimising their design. For example, Shinkansen, Japan's high-speed bullet train, plays an important role in Japan with a coverage of close to 3000 km. It has been operating for many decades now, from 1940. The earliest ones were operated by steam engines to reach peak speeds of 170 km h^{-1}. The maximum speeds that are technologically possible and the operational speeds of bullet trains have steadily increased. In 1989, the operational speeds had reached high enough levels, say 270 km h^{-1}, to cause sonic booms when they exited tunnels. In residential localities, this sonic boom caused significant difficulties to the public.

To address the sonic boom problem, a team was assembled. The team had many departments and the head of one of the departments, Eiji Nakatsu, believed in learning from nature—his hobby was bird-watching. He was fascinated by the silent, smooth, and high-speed swoops of birds such as kingfishers and owls. The kingfisher's beak was noticed for its efficiency to slice through water to catch a fish. The owl's silent swoops were noticed and related to its serrated feather design. Based on those and other aspects with a parallel to nature's designs, the Shinkansen was re-designed with a pointed front similar to the beak of the kingfisher (Figure 1.1).

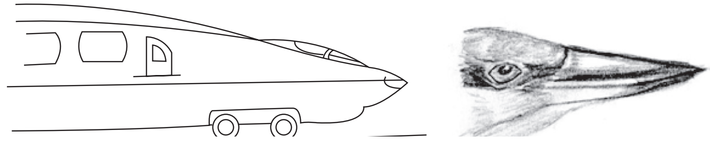

Figure 1.1 The nose of the re-designed Shinkanzen, shaped like a kingfisher's beak

The pantograph, the part that connects the train to the electricity supply lines above, was designed based on owl's serrated feathers and other natural features. The redesigned train was not only acceptably quieter when it exited the tunnels in dense residential areas, it was also 10 per cent faster and 15 per cent more energy-efficient. Biological features were mimicked to solve engineering problems and the results exceeded expectations. In fact, an entire field called *bio-mimetics* is a study of these fascinating aspects. In bio-mimetics, there are many specialized areas such as:

Bio-robotics It refers to robots that are inspired by biological entities or the use of biological components in robots. We are possibly familiar with the concept of bio-robotics from many sci-fi movies and TV shows, which show robots with human like features (e.g. the character, Data, in the hugely popular, 'Star Trek'). In reality, there have been many initiatives such as 'artificial sensing skin', which can detect pressure changes upon touch, robots inspired by animal movements, and softer robots that interface with the body for various prosthetics, or to provide insights into the working of natural systems. These softer bio-robots provide distinct advantages over rigid robots that are traditionally used for various automated operations, for example, in the assembly line for cars. The bio-robots can be used to perform intricate tasks which the traditional ones cannot perform. More recently, a number of androids (human-like robots) have even passed the Turing test, a test devised by Alan Turing to differentiate between humans and robots.

Muscular Bio-polymers These refer to specialized biopolymer nano-composites that can be used for artificial muscles, and so on. These specialized materials aim to have properties that are close to biological muscles such as excitability, contractility, elasticity, and extensibility.

The above example is only one advantage of engineers knowing biology, that is, inspiration or help with solutions to challenging problems. If we look further into history, it is well known that bird flight inspired the discovery of modern aeroplanes. Biology is full of solutions to current, highly significant challenges such as sustainability. Life has existed on earth for billions of years, whereas the so-called 'evolved life forms' such as primates have been on earth for only about 65 million years and humans for only about 5 million years, according to the scientific evidence. Life forms have evolved over billions of years and have harmoniously co-existed with their respective environments. Life has worked out highly sustainable ways over billions of years—life molecules are recycled in an effective fashion.

1.1.2 For Our Wellness—We Are All Biological Entities

The understanding of our biological selves is nowhere near complete. It is a challenge to ensure our physical and mental wellness. The brain, which controls most life processes in the human body, is yet to be substantially understood despite intense efforts. However, engineering appropriately coupled with biology has helped improve our biological shortcomings or partially overcome our biological losses.

Examples

Retinal Prosthetic Let us now consider one of the many examples where the inputs from many engineering fields were effectively harnessed along with biology to provide eye-sight to people who could see due to retinal diseases such as macular degeneration.

When an eye 'sees' something, its lens projects an image onto its retina and its photoreceptor cells, where the image gets converted to appropriate codes. The codes, in turn, get converted to corresponding electrical signals by appropriate cells located just behind the retina (Figure 1.2). The electrical signals are conveyed to the brain where the image is interpreted. All this happens in milliseconds or less that we are able to visually perceive the happenings around us in real time. When the retina gets diseased, the relevant cells die and the image no longer gets converted to appropriate codes. Scientists have developed a device, a prosthetic, that can convert optical images to codes and later to electrical signals, which can be transmitted to the brain. The prosthetic is small enough to be placed inside the eye at the retina and it is connected to the cells that transmit the signals to the brain. Thus, the person who is blind due to retinal disease can see again. Versions of this device are already approved by the U.S. Food and Drug Administration (FDA) for use on patients.

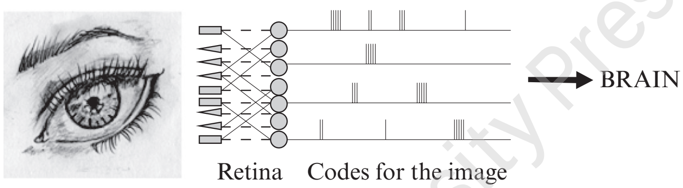

Figure 1.2 Image processing by the eye and brain

Let us consider the engineering fields that contributed to the above useful retinal prosthetic. Clearly, computer science principles were used to develop the relevant codes. Principles of electrical engineering, mechanical engineering, materials engineering, biological engineering, etc. were utilised to construct the device, to ensure its bio-compatibility and to facilitate its implantation for long-term use in the eye. All the engineering principles were appropriately used in combination with biological principles to make a successful prosthetic. Without the knowledge of the structure and functioning of the cells, it would have been impossible to make a successful prosthetic.

If one considers the other direction of information flow, from the brain to the body peripherals, principles of biology and many engineering fields have been combined effectively to create devices that can be operated by thought-generated electrical signals. Thus, people who have lost limb or part-body function due to accidents or diseases can move again.

Next, let us see some of the terms that seem to catch the fancy of the uninitiated. Bio-sensors, bio-chips, bio-pesticides, bio-fertilizers, etc. are some of the attractive terms that a student may have come across in their earlier reading, which have a biological base or significance. For better appreciation of the same, one can do the exercises given in the reflection point 1.2.

Bio-sensors These are devices that are used to measure many different parameters such as analyte concentrations. They are used for diverse purposes such as analysis, toxicology, medical diagnosis (i.e., they can even be incorporated into *digital plasters* to monitor the healing progress of wound), environmental monitoring, and others. In principle, they have miniaturised detection elements to measure, for example, the current or the voltage that are generated in proportion to the analyte concentrations or in relation to activities of different organs in the body such as the heart or the brain.

Bio-chips These are miniaturised laboratories in which thousands of biochemical reactions can be carried out simultaneously at micron scales for useful purposes such as disease studies or safety studies. Flow occurs at micron scales—principles of microfluidics are essential to design the bio-chips. Micro-fabrication skills are necessary to design and manufacture bio-chips. Many sensors are miniaturised and placed in a small area to measure the needed values.

Bio-pesticides These are organisms that can be used instead of chemicals for pest control and thus they overcome the negative effects of chemical pesticides. In the same vein, *Bio-fertilizers* are fertilizers that are composed of appropriate microorganisms. Chemical fertilizers improve the fertility of soil by adding chemicals such as N, P, and K. On the contrary, bio-fertilizers incorporate into relevant plant parts and provide the needed nutrients through biological processes called fixing. They help the plant to grow better by better fixing nitrogen, by better solubilizing phosphorus, or by improving the production of growth promoting substances by the plant itself. Bio-pesticides and bio-fertilizers have been known for many decades now.

Concrete Self-heal Organisms can be used to make *concrete self-heal* its cracks due to wear-and-tear. For example, some bacteria can catalyse the formation of calcium carbonate in their surroundings under appropriate conditions. When this happens in cracks that are formed in the concrete, the microscopic cracks are filled with the calcium carbonate formed with the help of the bacteria, which can effectively seal the cracks, and thus effect self-healing of the concrete.

Bio-filters These are essentially sand columns containing organisms that are used in wastewater treatment. They can be used on a large scale to provide clean water to large areas such as fields and ponds. They can also be used on smaller scales to purify water for home-use in challenging regions of the world. They are accessible, sustainable, and affordable. When contaminated water passes through the sand and the complex ecosystem inside it, the contaminants in the water are removed to yield potable water. More recently, it has been suggested that the fibres made by microorganisms themselves can be used as effective bio-filters to convert contaminated water potable. The fibres secreted by some microorganisms create a natural mesh with pore sizes less than a micron, and thus, they can operate as effective bio-filters.

Nanoparticles These are particles of various shapes with sizes in the range of a few to a hundred nanometers. They have specialized physical and chemical properties because of their small size, which make them suitable for use for specialized needs. For example, *Nanoparticles for drug delivery* have been developed, which are effective in delivering anti-cancer drugs to cancer cells, without affecting normal cells. Nanoparticles made of a suitable, bio-compatible material can be coated with agents that recognise cancer cells. Another coating on the same material is the drug that can kill cancer cells. Thus, we have 'bullets' that can home in preferentially to cancer cells, attach to them or go into them, and destroy them using the attached anticancer drug.

Organ-on-a-chip It is a micro set-up to test the effect of say, new drugs or toxins on representative animal tissues without actual animal studies. Microfluidic devices with small membranes and other support structures that can hold specialized organ cells are used to create the organs-on-a-chip. Body fluid-like materials that can flow on either side of the membrane, provide a functional representation of the real organ. Drugs to be tested are dissolved in those body fluid-like materials that are contacted with the tissue to test their effects on the organ tissues. Many years ago, the relevant tissues of organs such as lung, kidney, and others were developed to test the effect of drugs. The claim is that these organs-on-a-chip are closer to the human situation than the animals are, and thus the predictions could be much better. In addition, they could end the use of animals for drug-testing, which is a desirable scenario.

Further, whole *organs* can potentially be *3-D bio-printed* for various study purposes. It may be known that a 3-D printer is used to print many useful products. Even whole houses or parts of them can be 3-D printed and assembled together. However, 3-D bio-printing is a challenge because the biological cells need to be kept alive and vibrant during processing and printing. Cells need suitable nutrition and environment to be active, and techniques are being developed to maintain cells under desirable conditions during the 3-D printing process. The printing solution or gel is infused with the nutrients needed for the cell. The shear forces that the cells feel when they are extruded through the jets during the 3-D printing process also need to be minimised. A lot of research is currently underway to improve the success of 3-D printing. With further developments, the 3-D bio-printed organs can be used for organ transplants in the future. They could also eliminate the need to use animals for drug testing.

In addition, even methods for machine learning (*neural networks*) and methods to solve mathematical problems (optimisation) have been inspired by biological processes.

Artificial Neural Network The artificial neural network (ANN), a processing set-up, is supposedly inspired by the working of animal brains—they learn by example. ANNs are made up of a large number of interconnected elements, each of which work similar to a biological nerve cell. ANNs can be used to derive useful information from imprecise data. For example, they can be used to detect patterns or trends in complicated data that are difficult to detect by manual inspection. *Genetic algorithm* is an example of a mathematical optimisation method that is inspired by biological processes—the recombination of genes in this case. We will learn about genes in detail in later chapters.

Bioinformatics, Systems Biology, and Computational Biology These are currently popular fields of study which are highly multi-disciplinary, and engineers can significantly contribute to those fields. Those fields of study computationally analyse very large data sets to draw insights into the working of the fundamental functional unit of life—the cell. As we will see later in the book, there are many thousands of reactions that simultaneously occur in the cell as a part of its normal function. We will also see that the genetic information is contained in a polymeric molecule that has 6 billion units in every single cell of the body. To make sense of such large data sets, people with backgrounds as diverse as computer science, biology, biochemistry, biological engineering, electronics engineering, and many others, need to come together.

1.1.3 Scholarly View

Understanding something for the sake of it without any encumbrances of its application is probably the highest and purest academic activity. Many such aspects have found applications much later—sometimes even hundreds of years later. The classic example is electricity. Michael Faraday, a pioneer in electricity, was supposed to have said to William Gladstone, a popular politician, the famous words, 'One day, Sir, you may tax it' when the latter asked him about the use of ivory-tower research into something called electricity. We now know what an understatement it is about electricity. Another example of such a scholarly activity is the work in the 19^{th} century by Gregor Mendel on inheritance using pea plants. Mendel was a monk and he systematically studied the various characteristics of a large number of pea plants after diligently recording his large number of observations. His studies helped the understanding of inheritance of characteristics after more than a century. Moreover, we still use those principles as a simple means to predict diseases in children of parents with certain types of diseases, as we will see in Chapter 10.

Many important contributions are expected to be made in this century, the 'century of biology', to understand life, ourselves, and to make a sustainable life for ourselves. Engineers are expected to be at the forefront of many such contributions. This book is designed for them to overcome their possible fear of biology and address biological aspects with confidence. Since biology is predominantly information based as of now, engineers could also play a role in the consolidation of that information in terms of unifying principles, properties, etc.

REFLECTION POINT 1.1

1. Can you recall the reasons given in section 1.1 for engineers to know biology?
2. Do you have any thoughts on how each of the three major aspects discussed in section 1.1 can be improved with other aspects of biology that you may have come across?
3. Watch the following video to know more about biosensors:
   Title: 'Biosensors'; available at: https://www.youtube.com/watch?v=8zbcib44XCc
4. Watch the following video to know more about bio-chips:
   Title: 'What is BIOCHIP? What does BIOCHIP mean?'; available at: https://www.youtube.com/watch?v=tJPpdpK_IQ8
5. Watch the following video to know more about organ-on-a-chip:
   Title: 'Organs on chips – Wyss Institute'; available at: https://www.youtube.com/watch?v=Mg2fJ0UBj_0
6. Watch the following video to know more about bio-fertilizers:
   Title: 'Bio Fertilizers'; available at: https://www.youtube.com/watch?v=QV-kIt6wHok
7. Watch the following video to know more about nanoparticles used in cancer drug delivery:
   Title: 'Nanoparticle drug delivery'; available at: https://www.youtube.com/watch?v=fmnBF_gH6Lo

8. Watch the following video to know more about 3D bio-printing of organs:
   Title: '3D bioprinting of organs'; available at: https://www.youtube.com/watch?v=i8uCs09BoNU
9. Watch the following video to know more about self-healing concrete:
   Title: 'Self-healing Bio Concrete Repairs Its Own Cracks'; available at: https://www.youtube.com/watch?v=IaqACVY1U_k
10. Watch the following video to know more about neural networks for machine learning:
   Title: 'But what *is* a Neural Network? …'; available at: https://www.youtube.com/watch?v=aircAruvnKk
11. Watch the following video to know more about Bio-robotics:
   Title: 'Bio-robotics: Smarter Softer Robots (Harvard)' available at: https://www.youtube.com/watch?v=JZg7ouRvbas
12. Watch the following video to know about Chloe, the first robot to pass the Turing test:
   Title: 'Detroit: Become Human | Chloe …'; available at https://www.youtube.com/watch?v=oL1ZOLo3s7s

1.2 LEARNING BIOLOGY IS FUNDAMENTALLY NOT DIFFERENT FROM LEARNING MATHEMATICS

Many engineering students in our country, on their own or by peer pressure, seem to have the following hierarchy strongly set in their minds:

Highest position: Mathematics

Second position: Physics

Third position (lower than the second position by a big margin): Chemistry

Last position (much, much lower, even if one assumes it exists): Biology

The respect and consideration of a typical engineering student for the above subjects seems to be heavily dependent on the above hierarchy. Needless to say, the hierarchy has no proper basis except a 'social' one in engineering context. It is not necessary that the students who subscribe to the above hierarchy are particularly proficient in mathematics; in fact, many of those students may be uncomfortable with mathematics, but still they hold onto the hierarchy. This mindset makes it difficult for such students to even look at biology with an open mind.

Now, let us consider how we learnt mathematics in primary school and beyond. In primary classes, we learnt that there are numbers, say 1, 2, 3, and so on. Those numbers can represent many things and can be used to count anything, such as fruits, play things, etc. We then learnt that we can perform simple useful operations with the numbers. For example, if one holds five marbles in one hand and seven marbles in another hand, how many marbles does the person hold? We learnt that addition operation (an abstract concept) can be performed on numbers that represent the counts of say, marbles, and hence addition can be employed to find the total number of marbles, that is, $5 + 7 = 12$. By the time we are undergraduate students, we have employed the abstract concept, addition, on another abstraction, numbers, so many times that we do that with great ease without conscious consideration of the background. Similarly, the subtraction operation can be performed on numbers and it can represent many different real-life scenarios. Usually, at the undergraduate stage, we are highly comfortable with addition, subtraction, and the other two basic mathematical/arithmetic operations—multiplication and division, because we have done them so many times, each.

Then, let us consider the trigonometric functions. Some may recall the initial confusions—Is sine equal to opposite side by hypotenuse of a right triangle, or is it adjacent side by hypotenuse? Where do the roots of the cosine function lie in a graph? And so on. By the time we reach the engineering undergraduate level, we have practiced the basic trigonometric functions so many times that we are reasonably comfortable with them. Still, the comfort level may not be the same that we have with the four basic arithmetic operations.

Next, let us consider the log function. What is the value of $\log_{10}100^5$? For an average engineering student, the comfort level with the log function is not as much as with the four basic arithmetic operations, possibly because it is not encountered as frequently as the four basic arithmetic operations. An average student needs to recall the definition of log and then manipulate the given form to a form that is recognised in terms of the basic definition and solve it.

Now, do you recall what an error function is? Or, what is a Bessel function? That is tough, isn't it? In surveys done at IIT Madras, less than 5 per cent of the third year undergraduate class could even vaguely recall the error function and not even one could recall the Bessel function. Error function and Bessel functions are also mathematics. The students are usually introduced to these functions only during their undergraduate studies and have not used it as extensively as say, the four basic arithmetic operations.

Therefore, it can be seen that we need to *know* or *remember* the mathematical aspects, to apply them, much the same way we remember people's names. After using them many times we may not be consciously aware of the recall and may feel comfortable in that aspect for straight-forward applications. In this context, from the above argument it is clear that there is no basic difference in the way one learns mathematics or biology. The ease of initial learning will depend on the natural orientation of each person, but there is no basic difference in the way one learns mathematics or biology.

Let us now look at physics. Lots of observations were made by many scientists over the past many centuries. For example, falling apple, the speed at which simple objects move, the behaviour of charged species in electromagnetic fields, and many others. Scientists discovered that there were natural laws that govern the above, which can be mathematically expressed for completeness. The rules were reasonably universal too. However, in biology, we are in the phase of the field, which is dominated by observations. The rules in biology are not yet universal—there seem to be exceptions to many rules. The understanding is comparatively rudimentary and the mathematical representations are evolving. This is an exciting phase of development to be in for any subject and that happens to be biology now. In addition, the complexity in biology is far more than in the physical sciences.

The following chapters will focus on the essential principles of biology that are relevant for an engineering undergraduate in an easy to understand fashion. Ample directions to further learning of any topic that a student gets interested in, will also be provided.

REFLECTION POINT 1.2

13. Do you recall how you learnt probability?
14. Do you recall how you learnt calculus?
15. From a reliable web-source or a good engineering mathematics book, look up the forms of error function and Bessel function.

ADDITIONAL INFORMATION

1. The video titled, 'The world is poorly designed, but copying nature helps', talks about the Shinkansen sonic boom solution and also presents many bio-mimicry examples. It is available at: https://www.youtube.com/watch?v=iMtXqTmfta0
2. Additional bio-mimicry discussion is available in many other videos. For example:

   Design through bio-mimicry: Video title: 'Biomimicry. When nature inspires design', available at: https://www.youtube.com/watch?v=ZODvr_GzNc4
3. Another example: Bio-mimicry for a sustainable world–Janine Benyus

   Video title: 'What is biomimicry?', available at: https://www.youtube.com/watch?v=FBUpnG1G4yQ
4. The following link provides an interesting 2011 Ted Talk by Professor Sheila Nirenberg on artificial retina. You may want to think about the link to your own engineering field when/after you watch the video. Video title: 'A prosthetic eye to treat blindness', available at: https://www.ted.com/talks/sheila_nirenberg_a_prosthetic_eye_to_treat_blindness
5. The following video provides some information on brain-computer interface:

   Video title: 'Brain-computer interface: Mysteries of the brain', available at: https://www.youtube.com/watch?v=7t84lGE5TXA

POINTS TO REMEMBER

1. A knowledge of biological principles is essential for an engineer to make meaningful contributions.
2. Biology can help us design effective sustainable solutions to pressing challenges.
3. Biology can help us understand ourselves better, which would lead to a better quality of life.

4. Many scholarly contributions are possible in biology.
5. In principle, learning biology is no different from learning mathematics.

SUMMATIVE ASSESSMENT

MULTIPLE-CHOICE QUESTIONS

1. If an engineer knows biology, which of the following are valid statements?
   (a) The engineer can effectively contribute to engineering aspects of biological systems
   (b) The engineer can improve the understanding of biological information
   (c) The engineer will be shunned by his peers
   (d) The engineer will be apologetic about his position to his supervisors
2. In the development of the artificial retina, which of the following engineers probably played a role?
   (a) Electrical engineers
   (b) Computer scientists
   (c) Ocean engineers
   (d) Biological engineers
3. Engineering students are comfortable with the four basic arithmetic operations because all engineering students:
   (a) Have a natural orientation toward mathematics
   (b) Have used the four basic arithmetic operations an innumerable number of times
   (c) Know shortcuts to all four basic arithmetic operations
   (d) Are highly smart
4. The surveys done with undergraduate students at IIT Madras showed that:
   (a) All students could not recall the error function
   (b) All students could not recall the Bessel function
   (c) Most students could easily recall the error function and Bessel function
   (d) No student could recall the error function and Bessel function
5. Which of the following statements are not valid for the field of physics?
   (a) Physicists made a lot of observations over the past few centuries
   (b) There are rules that govern physical phenomena
   (c) None of the rules that govern physical phenomena are universal
   (d) All physicists are scared of biology

6. What are biosensors?
   (a) Devices to provide light
   (b) Devices that can provide heat energy
   (c) Devices that can measure relevant analyte concentrations
   (d) Devices that can measure relevant signals from the body
7. What are bio-fertilizers made of?
   (a) Microorganisms
   (b) Chemicals alone that can kill pests
   (c) Elements such as N, P, K, alone
   (d) Microorganisms that only kill pests

ANSWERS

1. (a) & (b) 2. (a), (b), & (d) 3. (b) 4. (b) 5. (c) & (d) 6. (c) & (d) 7. (a)