C. George Thomas

Research Methodology and Scientific Writing

2nd Edition

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Preface to the Second Edition

I am very happy that the first edition of the book *Research Methodology and Scientific Writing* was a hit among both researchers and research students. The first edition was published in 2015, by ANE Books, and a revised edition became a necessity within this short period because of the accumulation of huge quantum of new information in the subjects covered since 2015. Before attempting the revision, I have taken into consideration responses from the publishers, colleagues, and students.

This thoroughly revised and expanded edition is with several new features. The book comprises of 24 chapters, and each chapter is further divided into sections of specific units. Considering the demand of the readers, four new chapters have been added. A chapter exclusively on 'units and numbers' has been added considering the necessity of adopting only SI units in scientific measurements. I expect that a good number of students who are currently pursuing higher studies may join as lecturers or assistant professors. A chapter on 'Guidelines for Successful Lecturing' has been added for those who would choose a teaching career. A chapter has been set apart for 'Note making, Note-taking, and Assignments', which can boost the learning outcomes of students. The chapter 'Plagiarism: Prevention and Cure' has been added to warn researchers the perils of plagiarism and to take corrective steps.

Other chapters have been restructured with addition of new materials. By splitting the chapter on 'Approaches to Research', an additional chapter 'Major Research Methods' has been added with more inputs on the section, participatory learning and action. The chapter 'Information sources' has been split into two, 'Publications and the Library' and 'Academic Databases'. The chapter on 'Academic Databases; has been rewritten by deleting some non-functional databases and adding several useful ones with the latest trends and weblinks. Similarly, the chapter on 'Scientific Writing: Improve Your Writing Skills' has been split into three with additional information. The chapter on 'Preparation of Thesis and Research Papers' has been split into two, devoting a chapter entirely for thesis writing. The chapter on 'References: How to Cite and List Correctly' has been restructured by adding new trends in referencing with several new examples.

The revised edition has the same goals as the previous edition. With the restructured and additional contents, I am sure you will find the book more informative and useful.

Thrissur, India C. George Thomas

Preface to the First Edition

Thesis or dissertation is a mandatory requirement for the award of postgraduate degrees in most disciplines of science and technology. Because successful completion of research work within the stipulated time is necessary for the award of degrees, pressure on students as well as research guides would be very high. However, majority of students enrolling for a research degree have little knowledge or experience of research and may not be clear about the exact topic they wish to investigate. As research guides are often occupied with other work, they may not have enough time to instruct their wards on various aspects of practical research. Often, the students have to learn every step by themselves. Having recognized this issue, many universities in India have introduced compulsory coursework on 'research methodology' for their postgraduate students.

Recently, the University Grants Commission (UGC) has recommended compulsory course works of one semester for Ph.D. and specified that one course must be on 'research methodology'. Similarly, the Indian Council of Agricultural Research (ICAR) has suggested certain common compulsory courses for postgraduate education in agriculture and related disciplines in the country, which include 'Technical Writing and Communication Skills' and 'Library and Information Services'.

In Kerala Agricultural University, a compulsory course on research methodology with a common syllabus has been in existence for a long time, and I have been associating with it for the last 16 years. My search for reference books to teach this course revealed certain interesting facts. Most of the books on 'research methodology' available in the library are written for social sciences! Probably, the major reason is the peculiar research methods, especially of the qualitative type, social scientists follow. Although there is no dearth of books on experimental design and statistics, books on how to plan, write, and speak on research are miserably low. This compelling situation prompted me to write a book covering all the practical aspects of research.

The book, Research Methodology and Scientific Writing, is primarily meant as a handbook for beginners in research—research students as well as young scientists. It can also be used as a textbook wherever a course on 'research methodology' or 'scientific writing and presentation' (or on similar subjects) is offered. The book deals mostly with interdisciplinary fields such as finding research problems, writing research proposals, obtaining funds for research, selecting research designs, searching literature and review, collection of data and analysis, preparation of thesis, writing research papers for journals, citation and listing of references, preparation of visual material, oral and poster presentation in conferences, and ethical issues in research. Besides introducing library and its various features in a lucid style, the latest on the use of information technology in retrieving and managing information through various means have also been provided. Another major highlight is the inclusion of tips to improve writing skills of research students. A brief introduction to historical and philosophical aspects of research including methods and tools of science has also been given.

The driving force behind this book is the numerous postgraduate students I have taught during the last several years. I acknowledge the help and cooperation from several of my colleagues and friends. I remember with gratitude Dr. E. Ahmed, Professor of Agricultural Extension (presently, Director, Centre for E-Learning), who asked me to join the research methodology team at the College of Horticulture, Vellanikkara. I am thankful to Dr. Meera V. Menon, Associate Professor, and my colleague in the Department of Agronomy for going through the manuscript and offering several useful suggestions. My thanks are also due to Dr. C. T. Abraham, Professor and Head, Department of Agronomy, for his encouragement. I also acknowledge with thanks the permission given by the Kerala Agricultural University to print and publish the book.

I appreciate the cooperation and sincere efforts of Mr. Sunil Saxena, Mr. Jai Raj Kapoor, and their team at Ane Books, New Delhi, for bringing out the book in time.

I earnestly request the readers to feel free to bring to my attention discrepancies and omissions, if any, and suggestions for improvement.

Thrissur, India C. George Thomas

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About the Author

Dr. C. George Thomas is Retired Professor and Head in the Department of Agronomy, Kerala Agricultural University, Thrissur. He held the post of Associate Dean, College of Horticulture as well. He has more than 36 years of experience in teaching, research, and guiding students. Dr. Thomas obtained M.Sc. (Ag.) from Kerala Agricultural University and Ph.D. from Indian Agricultural Research Institute, New Delhi. A renowned science writer, Dr. Thomas has authored 16 books, 90 research papers, and over 250 other articles. He is a recipient of the Karshaka Bharathi award of Govt. of Kerala for his contributions towards farm journalism.

Chapter 1
Research: The Search for Knowledge

We know very little, and yet it is astonishing that we know so much, and still more astonishing that so little knowledge can give us so much power.
Bertrand Russell (1872–1970)

Human beings have been curious from the very beginning. Primitive humans observed matters concerning the universe, and changed their way of living, settlement, food habits, social institutions, and many others over time. In fact, these were the results of 'research' done by our ancestors on the processes happening in nature, which helped them to learn many lessons and draw several conclusions. Our ancestors used observation as the primary means to understand various phenomena. They invented many devices and tools by trial and error. Discoveries or inventions by accident were galore. Nevertheless, the pursuit of humans to unravel the mysteries of the universe had to face many challenges.

Earlier efforts of our ancestors to explain the operation of the universe paved way for primitive religious concepts; and for many phenomena, they attributed the cause to supernatural powers. This gave birth to religions and priests. At least for some part of history, religions became the authority on everything, even on science! Yet, there were many 'researchers' among them who could observe cause–effect relationships for various phenomena and processes. They also discovered that under certain conditions, events could be predicted with reasonable accuracy. The saddest part of the story is that often these findings and explanations were simply rejected, if they seemed to conflict with the prevailing religious dogmas. Nobody was allowed to question religious authority, and those who dared faced the consequences—sometimes even death! In course of time, however, humans could break the religious hold on matters concerning science. This emboldened them to have a quantum leap in science and technology, and they succeeded in offering accurate explanations for innumerable phenomena. In fact, the accumulated knowledge over the centuries was the result of 'research' done by our ancestors.

This process of research in search of more and more scientific knowledge is still going on in all the scientific disciplines.

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1.1 Acquiring Knowledge

What is known is knowledge. From the day we are born, we begin to acquire and refine knowledge in many ways. Acquiring knowledge and sharing it with others are widely recognized as the basis for improving one's power, especially reputation and influence in the society. Every addition to scientific knowledge is an accession to human powers. Francis Bacon (1561–1626), considered as the 'father of scientific method', recognized this power of knowledge and said, 'Knowledge is power', implying that with knowledge one's capability to succeed in life would surely increase. Bertrand Russell (1872–1970), a renowned philosopher of the twentieth century, recognized the power of knowledge; he said: 'We know very little, and yet it is astonishing that we know so much, and still more astonishing that so little knowledge can give us so much power'.

Knowledge can refer to both theoretical and practical understanding of a subject, which includes facts, descriptions, information, and skills acquired through experience or learnt through books or other means. In other words, knowledge can be *implicit knowledge* as with practical skills or *explicit knowledge* as with the theoretical understanding of a subject. *Information* is knowledge communicated through any media such as sensible statements, opinions, facts, concepts, or ideas. Information becomes knowledge only when it is conceived and understood.

The knowledge we acquire may be a priori (a Latin term, meaning 'prior to') or a posteriori (posterior to). Note that the knowledge known independent of experience is a priori. It is non-empirical or arrived at beforehand without experience. In contrast, a posteriori knowledge is knowledge known only by experience. It is empirical or gained only after we have firm experiences.

We consider a priori knowledge as true, because *deductive reasoning* is used to arrive at that conclusion using valid arguments. For example, the knowledge that 7 plus 5 is equal to 12 is known without direct experience. Anybody with some arithmetical understanding will be able to tell the answer. In other words, we acquire a priori knowledge not through experience but by reason alone. Most of the equations in mathematics are examples of a priori knowledge, as they are self-revealing. Similarly, the statement, 'all dogs are mammals' is an a priori truth. By knowing the definitions of the word 'dogs' and 'mammals', one can use reason to establish that the statement, 'all dogs are mammals' is true without the need to examine all dogs for mammalian characters.

From *inductive reasoning* based on empirical evidences, we gather a posteriori knowledge. For example, a statement such as: 'this rose flower is fragrant' cannot be considered true through reason alone. You cannot be sure whether the rose flower in question actually possesses fragrance through reason; for that, you must have direct experience—you have to smell the flowers. Note that unlike a priori knowledge, this type of a posteriori statements can be faulty; the rose in the statement may not have fragrance! Although certain scientific disciplines such as physics treat all knowledge as empirical or a posteriori, some disciplines such as mathematics use logic and reasoning. Rationalists suppose that knowledge is primarily attained by a priori processes or is inherent, but for empiricists knowledge is a posteriori. Most scientific disciplines now utilize both a priori and a posteriori knowledge.

The discussion on knowledge leads us to recognize that acquiring knowledge is through acquaintance and through the description of characteristics of materials or phenomena. We learn many things through perception and sensation. However, most of our knowledge is by description. Knowledge may also take the form of beliefs and judgements. Some beliefs may be supported by evidences, but many are simply beliefs! The beliefs that are supported by evidences are 'justified beliefs'. According to the great philosopher Plato, knowledge is 'justified true belief'.

Kerlinger (1986) quoting Charles Sanders Peirce (1839–1914), a renowned American philosopher, described four methods of acquiring knowledge or fixing beliefs.

Method of tenacity: Probably because of our upbringing and socialization pattern, we believe and accept certain things to be true. These are being taught or thrust upon us from early childhood. Among the public, the more frequent the repetition of the belief, the more the enhancement of its validity. It is difficult to change such beliefs even in the face of conflicting evidences, and sometimes, fresh ideas may evolve from false beliefs or superstitions! For example, most religious beliefs, spirituality, omens, superstitions, and astrology existing in the society are through the method of tenacity or beliefs. People adhere to such beliefs, and it is very difficult to change them. The root cause of many superstitions in the society is because of this human habit of clinging to such dogma.

Method of authority: In olden days, nobody was allowed to question the authority. The authority might be kings, priests, or other leaders. People often take for granted the information passed on to them based on authority. Even now, the authority has some sway over the people. For common people, a statement must be true, if it is in the religious books. Most people also accept as true without questioning what the kings (now, political heads!), judges, priests, oracles, celebrities, leaders, or teachers say. The authority is considered infallible.

Although the 'method of authority' has several problems, it is considered to be superior to the 'method of tenacity'. Acquiring knowledge through authority is common among people because of some reasons. Most people are conditioned from birth by their parents with suggestions to listen, trust, and obey authorities. In most cases, authoritarian method is the fastest and most efficient method of transmitting knowledge. However, authoritarian knowledge should be corroborated by evidences and reasoning to consider it reliable. As far as science is considered, if we accept the authority of politicians or public figures like poets, artists, or other celebrities, that would be the end of science! The norm must be to accept only 'experts' in their own fields as authorities in science.

Method of intuition: The method of intuition or a priori method of acquiring knowledge is considered to be superior to the two already mentioned. As already discussed, it is called a priori method as reasoning is done from what is 'prior' or 'before'. The propositions accepted by the method of intuition are self-evident. However, in intuitive propositions, reason is considered as the criterion of truth rather than experience. It attempts to reason from cause to effect or from observed fact to another fact or principle not observed. However, if two reputed individuals reach different conclusions based on intuition, it would be difficult to decide for sure whose judgement is correct.

Method of science: The method of science or scientific method is a practical methodology of acquiring knowledge by framing specific questions and systematically finding answers. Among the four methods of acquiring knowledge, scientific method is the most reliable. In this method, the questions formulated and answers predicted are scrutinised based on observation, measurement, verification, and evaluation. The method of science is based on empirical and measurable evidences rather than beliefs or arguments. This unique characteristic distinguishes science from other methods of faith, authority, or intuition. Scientific method has also the rare characteristic of self-correction, which no other method has; in science, theories and laws are revised based on new evidences (see Sect. 1.8).

1.2 Science and Technology

Can you define science exactly? In fact, the word 'science' is from *Scientia,* a Latin term, meaning knowledge; and it was originally used to mean simply knowledge. In Sanskrit, the word for science is *Vijnana*, which is associated with the processes of discernment and understanding. However, science as we understand today is much more than simply knowledge.

A major distinguishing feature of scientific knowledge in comparison to other kinds of knowledge is that it is not static. Scientific knowledge is constantly revised or expanded through the processes of observation and experimentation. Therefore, one can say that science includes a 'content' part and a 'process' part of acquiring or improving this content. Scientific knowledge hitherto known to us developed as the content of science. This 'content' is what we usually read and learn from science textbooks comprising of descriptions, facts, principles, theories, laws, and their relationships (Sect. 1.7). The 'content' of science develops through the 'process' of science involving repeated observation and experimentation done in a methodical manner. This 'process' is nothing but *research* using scientific method (Sect. 1.8). The stipulation of methodical approach to acquire knowledge in science is important because this distinguishes science from other knowledge systems prevalent in the society.

The above discussion leads us to define science as follows: Science is a body of knowledge attained through repeated observation and experimentation done methodically, which is always amenable to correction, modification, or improvement upon getting better evidences.

Science is closely related to *philosophy*. For a considerable period in the history of science, both 'science' and 'philosophy' were considered the same. Some distinctions between philosophy and science, however, began to surface during the late modern period. By eighteenth century, the use of the term 'science' in the sense of any systematic field of study began to get acceptance, distancing itself from ‘philosophy’ (For more historical details, see Sect. 1.5; and for a discussion on science and philosophy, see Sect. 2.1).

Do not confuse ‘science’ with ‘common sense’ although both have some similarities. Thomas Henry Huxley (1825–95) gave a definition for science based on its similarity with common science. According to him, ‘Science is nothing but trained and organized common sense differing from the latter only as a veteran may differ from a raw recruit: and its methods differ from those of common sense only as far as the guardsman’s cut and thrust differ from the manne’. If you consider both as knowledge, then, common sense is knowledge attained from information around us, but scientific knowledge is through observation and experimentation on a particular subject.

Broad Classification of Science Disciplines

It is common to divide scientific disciplines into natural sciences, social sciences, and humanities.

Natural sciences: The disciplines categorized as natural sciences deal with the study of the physical world and its phenomena through empirical methods. Natural sciences are concerned with the processes and phenomena that would occur in the absence of humans, and include the disciplines such as biology, chemistry, physics, astronomy, and geology.

Social sciences: Social science disciplines study the processes and phenomena arising from the activity of humans, for example: sociology, economics, and anthropology. Social scientists also make use of the scientific method to study these processes.

Humanities: Humanities deal with the study of culture arising out of human activities and achievements, for example: literature, art, languages, and theatre. In humanities, generally a critical or analytical approach is employed to study human culture.

Although social sciences make use of the scientific method, in academic circles, these are often considered as ‘arts’ along with humanities; and many people object to consider these disciplines as sciences, because, according to them, empirical methods are seldom possible to apply in such disciplines.

Applied Science, Technology, and Engineering

Natural science disciplines are usually described as *basic sciences* and *applied sciences*. The disciplines that come under basic sciences, also called pure sciences, develop knowledge to predict, explain, and understand various phenomena occurring in the natural world. On the other hand, applied science disciplines apply knowledge from basic sciences to solve practical issues and develop applications. For example, agricultural entomology and medical entomology are applied fields of entomology contributing towards agricultural or medical knowledge for pest control applications.

Applied sciences, *technology*, and *engineering* are offshoots of science. Applied sciences utilize existing scientific knowledge and associated applications for specific purposes. However, technology is development or improvement of a device or appliance using already known principles and methods. Pure sciences help us to understand the world better through knowledge creation, but applied sciences and technology are for controlling the world and for making it a better place for human beings.

Some distinctions between *technology* and *engineering* are also needed. Technology is the field that applies science to solve problems with a commercial end in mind. The word is from *Technologia*, a Greek word, meaning systematic treatment of an art. The term 'technology' is generally used to explain new inventions and devices using recently derived scientific principles and processes. Although synonymously used in many circles, 'engineering' is a much broader term than 'technology'. It is used to denote an activity that applies human qualities such as imagination, critical evaluation, and intellectual thinking to existing human knowledge bases to create or utilize technology safely and efficiently. In addition to traditional branches such as civil engineering and mechanical engineering, now we have branches like bioengineering and genetic engineering, which may revolutionize life on earth in the future.

1.3 What is Research?

The literal meaning of 'research' is meticulous search. However, in popular usage, research is a systematic search for answering a particular question, solving a problem, or gathering information, especially for a project, literary work, cinema, or a television series. In academic fields, the term research is used to denote activities such as defining, redefining, and solving problems; observing facts and their interpretation; formulation of hypotheses and their testing through experiments; revision of existing theories and laws; and practical application of information already generated. Before the emergence of modern science, experimentation and scientific method were unheard terms, and the 'research' was mainly through *logical reasoning*. It is, therefore, quite natural that some of the basic distinctions in logic have carried over into contemporary research. Consequently, the *inductive* and *deductive* methods of reasoning (see Sect. 1.6 and Chap. 14) became part of modern science and research. *Logic*, *reason*, and *evidences* are essential parts of modern research.

Research in natural sciences and social sciences employ different methodologies and approaches based on the nature of disciplines. Objective measurements are far easier in natural sciences but comparatively difficult in social sciences. For example, in disciplines such as physics and chemistry, it is relatively easy to keep the conditions under control during experiments, and the results obtained by any researcher are testable and repeatable. However, as social sciences deal with phenomena arising from the activity of humans, it calls for a different approach to research. Understanding and studying human behaviour is a complex process, and therefore, the context of social science research keeps changing. This problem is apparent in most applied sciences such as agriculture and medicine too, which are also the creation of humans.

In most scientific disciplines, research is used as a tool to understand and solve problems for the benefit of people. Discovery of antibiotics for the treatment of diseases affecting humans or the discovery of fertilizers to take care of depleting soil fertility are examples. Similar to the above simple examples, several other examples of discoveries and inventions that made the life of humankind easier and comfortable can be quoted.

Research is also used as a management tool. Most managers use appropriate research techniques for routine as well as strategic long-term management. Research is used as a tool in defence for chalking out better strategies. In everyday life, even non-scientists such as journalists, judges, lawyers, police, scriptwriters, and artists make use of research to solve and settle issues related to their profession.

Motives for Doing Research

In earlier days, our ancestors dabbled in research because of necessity and the quest to unravel the unknown. At present, many people take up research as a career. Yet, some others pursue research as a hobby and become amateur scientists because of some specific interests. One or more of the following may be the motives in doing research.

Excitement of discovery: Many want to become scientists or researchers enthused by the chance of adding something new to the existing knowledge base. The excitement of discovery or invention is a strong motive to take up research. In fact, most of the breakthroughs happened in science were due to this quality of a few enthusiasts.

Pursuit of prestige: Scientists, who pursue a career in research, usually commands respect in society. The theories, principles, and other findings they make increase the status of scientists and may bring fame and glory to the researchers.

In depth knowledge on a subject: The person who undertakes research on a subject gets an opportunity to study that subject in depth.

Service to society: The society derives many benefits out of research. By using appropriate research techniques, the causes and remedies for many problems currently affecting the society such as food security and climate change can be found out.

Need for publications: For a successful career in an academic or research institution, publications are necessary especially to get promotions. In fact, many institutions rate their scientists based on the number and quality of publications made out of research.

Obtaining a higher degree: Students in agriculture or fields such as medicine and engineering need to submit a thesis or dissertation to get Master's degree. However, for a doctorate degree in any discipline, research and consequent report in the form of a thesis is mandatory.

Better management: Most managers use appropriate research techniques for routine as well as strategic long-term management.

A tool in defence: Research is used as a tool in defence for chalking out better strategies.

Research in everyday life: In everyday life, even no-scientists such as journalists, lawyers, police officers, scriptwriters, and novelists make use of research to solve and settle issues related to their profession.

Benefits of Conducting Research

The benefits of research are many to the society as well as the person who conducts research. Whatever be the motives of the researchers, the society enjoys the following benefits:

Expanding frontiers of knowledge: The 'body of knowledge' of various scientific disciplines expands through research.

New inventions and discoveries: This is the main objective of research in applied sciences and technologies.

Solving problems affecting the society: By using appropriate research techniques, the causes of many problems currently affecting the society can be found out and remedies suggested.

Increasing efficiency and reducing costs: Efficient machines and better problem solving increase the efficiency of work and reduce the cost of production.

Research strives to make life easier: Examples include better transport and communication facilities that made the world a better place to live in.

Luxury and comfort: Examples are many. Research for better houses, house materials, transportation, comfortable clothes, and many others provide luxury and comfort for a better living.

Infotainment: Information plus entertainment is infotainment. There are umpteen opportunities for entertainment now because of spurt in technologies. Computers, Internet, and smart phones made information retrieval and its dissemination fast and cheap.

Economic growth: Research is also needed for speeding up business, efficient factories, new products, new marketing strategies, and so on to ensure economic growth.

Characteristics of Good Research

The body of knowledge comprising various disciplines grows through research. Technological advancements in any field are through research efforts of numerous people. Good research is characterized by certain attributes.

Research is based on the work of others: Research is an activity based on the work of others. This does not mean that you are copying the work of others, but look to the work that has already been done to provide a basis for what and how you might conduct your work.

Research is a blend of logic and imagination: Research is guided by the rules of logical reasoning, and the logical processes of induction and deduction. Imagination and thought are used for making hypotheses and theories.

Research tries to identify and avoid bias: Evidences can be biased. Bias can occur during the planning of experiment, its implementation, data collection, interpretation, and reporting. Sometimes, nationality, gender, ethnicity, age, and political views of the researchers may influence them to go for biased evidences or interpretations. Possible sources of bias and how bias is likely to influence evidences and interpretations must be understood and precautions must be taken.

Repeatability: Repeatability is an important characteristic of good research. If we repeat the research, we should get the same results.

Research must be generalisable to other settings: Research is universal in nature. The findings and results obtained in one setting must be suited to other settings also.

Research is systematic: Scientific research is systematic and structured with specified steps in a sequence. Although it does not rule out creative thinking, it rejects mere speculation and intuition in arriving at conclusions.

Research generates new questions: An enquiry into a new phenomenon generates new questions, which must also be answered.

Research is an apolitical activity: Research is not authoritarian and should not have any 'politics' behind it. It should be undertaken for the betterment of society and not for selfish or destructive purposes.

1.4 Qualities of a Researcher

Researchers may have some inherent qualities. They should strive to attain qualities, which they may not have. The following are some qualities, which all the researchers must try to develop. Among these, the first two—the scientific attitude and research attitude—are the prime qualities every researcher should possess.

Scientific attitude: Attitudes are predispositions to react positively or negatively to some object. Scientific attitude is the attitude of a person to promote the use of scientific approaches and rationales to react to any object. Researchers should not succumb to superstitions, unfounded information, word of mouth, or pseudoscience.

Research aptitude: Not all those coming to the field of research may have a research aptitude. Researchers should be inquisitive and curious about things and events around them. They should have genuine interest in the subject and a mindset to unravel the unknown. In other words, they should have a 'research mind'.

Persistence: To become a successful scientist, one must be persistent and continue ahead of research through publications, especially peer-reviewed research papers. Persistence means the traits such as perseverance, patience, tenacity, thoroughness, and determination to achieve something. A researcher should be patient enough to wait for the results. Sometimes, they may not get the desired results within the stipulated time. Certain investigations are time consuming, involve drudgery, and require the help of many people. Undue hurry will not yield anything.

Self-motivation: Self-motivation is an important quality for scientists. Self-motivated scientists produce more results than others do.

Courage to ask questions: Researchers should ask questions about things, which they cannot agree or do not understand. They should ask 'what', 'how', 'when', and 'why'; and find answers by critically observing, experimenting, consulting, discussing, and reasoning.

Skepticism and receptivity: A critical attitude is essential for all scientists. Do not simply accept the data and interpretations. Evaluate them with an open mind. Strike a balance between skepticism and receptivity. You must always entertain new concepts and ideas rather than confronting them with a negative response or criticism.

Objectivity: The conclusion drawn by a researcher should be objective, and that it should be based on findings revealed through actual data. The researcher should strive to remain impartial to the outcome of the research, and ensure that prejudiced or emotional leanings of a researcher should not in anyway influence the conclusion.

Industriousness: Research is not an easy job. Those who are lazy and longing for comfort and luxury will not become a successful researcher, and the society will not gain anything from them. Researchers should aspire to make new discoveries and inventions by sustained and dedicated work. There is no retirement for good researchers.

Honesty and truthfulness: Researchers should be honest in their approaches. They should follow the established ethics, and should not commit any fraud or misconduct. They will record honestly the observations and experimental results, and try to avoid all types of plagiarism.

Open-mindedness: A researcher should be impartial. They should not have any pre-conceived notions or biases towards researchable issues. They will only be guided by facts, reasons, and logic.

Above-average intelligence: Scientists need not be super intelligent. It is often noted that intellectuals without the other needed qualities of a scientist seldom achieve anything in science. However, a scientist with above-average intelligence can succeed by hard work and performing better in other qualities required for scientists.

Knowledge: Researchers should be proficient in their subject. They should be willing to collect all the relevant literature connected with the researchable topic, read them critically, analyze them, and learn them.

Imagination: Imagination is essential for insight and for problem solving. Most scientists are surprisingly imaginative; however, when imagination is combined with both determination and a vision, the result can be wonderful!

Self-confidence: Self-confidence encourages motivation to tackle challenges and foster optimism.

Search for perfection: The researcher will repeat experiments carefully and systematically, if required, and will not manipulate results under any circumstances.

Team spirit: Certain problems cannot be solved by an individual scientist because of the vastness of the problem. Sometimes, the problem may be multidisciplinary, and a team comprising of experts from different disciplines is required. The researcher should be able to work in a team where personal ego or dislikes will not have a place.

1.5 History of Research

The age of earth is estimated to be about 4.6 billion years, and it is believed that life in the form of bacteria originated some 3.5 billion years ago. Human like beings (*Homo erectus*), the immediate ancestors of humans (*Homo sapiens*), first appeared on earth approximately 1.5 million years ago. It is also postulated that the first form of *Homo sapiens* evolved from these ancestors some 0.35 million years ago. Neanderthals and Cro-Magnons were early *Homo sapiens*. They transformed eventually to the present day modern humans (*Homo sapiens sapiens*) by about 40,000 years ago. Primitive humans lived on hunting, fishing, and by gathering food from nature. They could not continue this lifestyle for long because of population pressure and its effect on carrying capacity of their dwelling place. Humans with their experiences in hunting and gathering learned many characteristics of wild plants and animals. In the meantime, they also discovered and learnt the use of fire. As the pressure of population on their existing resources increased and their means of sustenance started decreasing quantitatively and qualitatively, they had to look for some other means to produce food. This search for alternate food production culminated in the discovery of agriculture.

The origin of agriculture was with the first domestication of plants and animals. The food gatherers and hunters became farmers by this development, which happened somewhere around 8000 BC by the end of the Mesolithic Age or the Middle Stone Age. The socioeconomic revolution initiated by this new development became famous in anthropological and archaeological literature by **Gordon Childe**'s phrase, '*Neolithic revolution*'. According to **Mark Cohen**, an archaeologist specialized in ancient cultures of coastal Peru, agriculture developed strictly as a response to population pressure (Cohen 1977). This gave credence to the argument that agriculture was born out of necessity. It is estimated that world human population was about 5 million only when agriculture began to take shape. Presently, after 10,000 years, it is more than 7800 million or 7.8 billion! (World population crossed 7.7 billion in Nov. 2018).

Before the arrival of agriculture, humans were probably contented with the satisfaction of their basic requirements of food and shelter only. The quest for secondary needs including clothing developed gradually, which called for more sophisticated technologies. In the primitive way of life, when humans depended solely on hunting, fishing, and gathering, they had limited time to devote to cultural activities, because the greater part of the day was spent in search of food to prevent starvation. Therefore, it is often argued that most of the characteristics of modern development coincided only with permanent settlement.

Humans have been inquisitive and learned many things based on observation and by trial and error. Our ancestors tried to explain various natural phenomena, paving the way for primitive religious concepts and religions. Some persons were designated as priests who explained every phenomenon as God's creation under authority. Priests began to claim special channels of communication with the gods leading to the establishment of a system of religious authority passed on from one generation to another. In course of time, a rigid dogma of nature's processes developed. Any deviation from religious teachings was not allowed, and those who dared to break the authority away from traditions faced dangerous consequences. This retarded the search for truth for centuries. The oppression and curbs from religious authorities on freethinking and scientific pursuits were most rampant in Europe during the 'Middle Ages' (fifth to fifteenth century), and this period is called the 'Dark Ages' of Europe. It is distressing to note that humans could wait up to about sixteenth century to break the religious hold on matters concerning the universe and offer accurate explanations for various phenomena!

The Birth of Science

In ancient Europe, '*philosophy*' was the term used to refer all types of knowledge including science. Before the eighteenth century, the present-day scientists were referred to as 'natural philosophers'; that is, philosophers who study nature, and the more common term for science was 'natural philosophy'. During the eighteenth century, the word '***science***' began to catch up in the sense of any systematic field of study. In the nineteenth century, people began to differentiate science from other forms of knowledge. The word 'science' became more popular after the establishment of the British Association for the Advancement of Science in 1831.

Philosophy and science, as we know them today, originated with the early Greek civilization. The period from 600 BC to AD 200 saw many eminent philosopher scientists; and for science, this period was a golden period. Around 300 BC to 400 BC, many Greek philosophers proposed natural explanations for phenomena that had previously been explained only by reference to supernatural myths or tradition. People in ancient times observed and believed *apparent truths.* The Greek philosopher–scientists proposed remarkably precise explanations for several natural phenomena. Along with these, they also proposed many mistaken explanations. This in no way, however, prevented them from continuing their pursuits to learn about nature. The Greeks believed that knowledge could be derived from *absolute truths* or *axioms.*

Great thinkers of Greek golden period, especially **Socrates**, **Plato**, **Aristotle**, **Hippocrates**, **Democritus**, **Aristarchus**, **Pythagoras**, **Euclid**, **Archimedes**, **Ptolemy**, and **Galen** made important contributions. An overview of important contributions of the most prominent Greek thinkers is mentioned below.

Socrates (469 BC–399 BC): Socrates was a great Greek scholar who taught people to question everything before accepting, and he maintained that self-knowledge is more important than knowledge of the universe. However, the establishment was not tolerant to Socrates, and he was brought to trial and sentenced to death by poisoning on charges that he was an atheist and corrupting youth.

Hippocrates (460 BC–370 BC): Probably, Hippocrates is the most outstanding physician in the history of medical science, who is known as the 'father of medicine' in recognition to his long-lasting contributions to the field. He is credited to developing medical science as a rational method. He is also associated with medical ethics, by coining what is now known as *Hippocratic Oath*, still being administered to new medical graduates.

Plato (429 BC–347 BC): A philosopher and mathematician, Plato was a disciple of Socrates. He founded the Academy in Athens, the first institution for higher learning in the west. According to Plato, knowledge of nature does not require observation; it is attainable through reason alone. However, problems arose as the Greeks began to accept many apparent truths as absolute truths. From earth, it appears that the earth stands still and everything else moves around it!

Aristotle (384 BC–322 BC): Aristotle was an exceptionally talented Greek philosopher-scientist, a pupil of Plato and the tutor of Alexander the Great. Although Plato's main interests were philosophy and logic, Aristotle dabbled in many areas of science along with philosophy. He wrote extensively on natural sciences; some even considers Aristotle as the 'first scientist' in the world. He set a pattern about earth and the universe that was to last for about 2000 years to come. For him, a large stationary earth is at the centre of the universe, and the sun, the moon, and the stars orbiting circularly around the earth. He also contributed considerably to the knowledge of biology. He classified animal species and arranged them into hierarchies. Aristotle formulated the now infamous *Scala Naturae* (the great chain of beings) to explain the diversities of living things. Accordingly, a rat was born as a rat and frog as a frog; all creatures remained unchanged as they were created as per the wisdom of God. This theory was accepted immutable as it was consistent with religious dogma, and no scientists dared to offer alternative explanations until the nineteenth century.

Euclid (325 BC–270 BC): The knowledge of geometry developed by Egyptians was perfected and presented in an axiomatic form by Euclid around 300 BC. Many of the geometric principles could be presented in a deductive system as with many theorems, which could follow logically from a few self-evident axioms or obvious truths. This must have made a deep impression on the Greek mind. Eventually, the notion that the behaviour of nature could be described using logic alone began to prevail. This is the essence of *rationalist philosophy.*

Archimedes (287 BC–212 BC): Archimedes contributed much for the advancement of science. He is famous for the floatation principles in physics. One important principle is named after him, the *Archimedes principle.* He calculated the value of 'pi' (π), and made known the mechanical advantages of lever and pulley systems.

Ptolemy (AD 90–AD 168): Ptolemy was a Greek-Egyptian, who influenced human belief regarding the organization of the universe for many centuries. He developed the now infamous *geocentric theory* of the universe in about AD 140. As Ptolemy's model agreed with the apparent movements of the heavenly bodies and because it was accepted as consistent with religious dogma, nobody dared to question his model for about 1400 years to come.

Galen (AD 129–AD 200): Galen was a Greek anatomist and physician who made invaluable contributions to the knowledge of anatomy and physiology. His theories remained unchallenged until the sixteenth century when new insights into human anatomy and physiology were made by Andreas Vesalius and William Harvey.

The Dark Ages

Logically, one might expect that human scientific endeavours would have grown rapidly following the great discoveries and logical methods introduced by the Greek civilization. What actually ensued should serve as a lesson for our modern scientific and technological world! After the decline of the Greek civilization, there was a decline in the practice of scientific logic. Autocratic political systems did not allow free thought. Although Romans were great administrators and soldiers, they were not scholars. Science and technology did not flourish under their rule as happened during the heydays of Greek civilization. Christianity and Islam, which rapidly spread during the period, also did not help much in the development of science. They accepted most of the knowledge gained by the Greeks as consistent with divine revelation.

The ‘Middle Ages’ or the ‘Dark Ages’ of Europe (fifth to fifteenth century) was a sad period for science as a whole (The Middle Ages is the central period of a three-period division of European history—classical, medieval and modern). Religion characterized by *dogmatic beliefs* (preconceived beliefs held to be true no matter what contradictory evidence might exist) wielded tremendous powers over politics and society at that time. Naturally, the rate of new scientific discoveries came to a standstill. This dark age of dogmatism prevailed for over 10 centuries. History shows us the importance of freedom to use scientific methods, if we are to continue to learn about nature. The period was, however, not dark all over the world. For example, **Aryabhatta**, **Varahamihira**, and **Brahamagupth** from the Indian sub-continent contributed much during this period. Important contributions of Indians were the numeral ‘0’ (zero) and decimals. Algebra was developed by the Arabs.

Revival of Science

Until the revival of science by the end of the Middle Ages, science and philosophy were considered together, and both science and philosophy had became bound with theology. From the philosophers of ancient times to the fifteenth century, the contributions to science were very negligible. However, science and technology advanced to boundless levels during the last 500 years, bringing an ever-more comprehensive view of the world. This was possible because of some radical changes that took place in Europe by the end of Middle Ages putting an end to the long period of ‘darkness’ in science. The period between AD 1500 and AD 1700 is considered as the age of ‘Revival of science’, and this was instrumental in effecting a change in the western attitude from the medieval to the modern. However, the Church and the emerging *empiricism* were at loggerheads, and the opposition of Church continued for about 200 years. Despite the opposition, new ideas in physics, astronomy, biology, human anatomy, chemistry, and other disciplines rejected many doctrines and beliefs prevalent in the society ultimately ushering in modern science.

In fact, three major inventions that happened during the fifteenth century were responsible for most of these changes. One of these was the invention of *printing*. Printing required the development of paper to replace parchment. Developed originally in China, the technique of papermaking reached Europe in 1200s, and by 1450, papermaking was common. The effective application of printing was achieved by Gutenberg in 1438. The printing press promoted literature and science. Because of the printing press, multiple copies of the Bible could be made available for the public. People began to read religious scriptures, and started questioning the teachings of religious authorities. Two other radical inventions that paved the way for revival were