Cover Page

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STRUCTURES OF BIOLOGY: HISTORY OF BIOLOGY TEACHING, BASIC CONCEPTUAL STRUCTURES OF BIOLOGY

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Abstract:
This document provides a comprehensive historical and conceptual overview of biology and biology education, tracing its evolution from ancient Indian scientific traditions through medieval interruptions, colonial influences, and major shifts in Western science. It examines the development of science teaching methods, including influential educators, landmark commissions, and national education policies in India that shaped modern science curricula. The paper highlights reforms introduced after independence, the growing emphasis on inquiry-based and student-centered learning, and the institutional role of NCERT, SCERT, and SISE in improving science education. It also explains the fundamental structure of biological knowledge—facts, concepts, generalizations, theories, and laws—along with the processes of scientific inquiry and the emergence of Biology Education Research (BER) as a field focused on improving conceptual understanding. Together, these discussions frame biology as both a historical discipline and a dynamic, evolving scientific enterprise with deep educational significance.

Keywords: Biology education, History of Biology, Science Education in India, Inquiry-Based Learning, Student-Centred Learning, National Education Policies, NCERT, SCERT, SISE, Biology Education Research (BER), Scientific Inquiry, Structure of Biological Knowledge, Curriculum Development, Educational Reforms

1.1 Introduction

"The progress, welfare and security of the nation depend critically on a rapid, planned sustained growth in the quality and extent of education and research in science and technology".

- ***Kothari Commission (1964-66)***

The word "biology" is a child of the twentieth century. Prior to that date there was no such science. When Bacon, Descartes and Kant wrote about science and its methodology biology as such did not exist, only medicine (including anatomy and physiology), natural history and botany (somewhat mixture). Anatomy, the dissection of the human body, was done far into the eighteenth century a branch of medicine and botany likewise was practiced primarily by physicians interested in medicinal herbs. The natural history was studied as part of subject natural theology. The scientific revolution in the physical sciences had left the biological sciences virtually untouched. The major innovation in the biological thinking did not take place until nineteenth and twentieth centuries. It is not surprising therefore, that the philosophy of science when it developed in the seventeenth and eighteenth century was based exclusively on the physical sciences and that it has been very difficult, subsequently, to revise it in such a way as to encompass also the biological sciences. It is only recent decades that several philosophers such as (Scriven, Beckner, Hull and Campbell) have attempted to characterize the diiferences between the biological and physical sciences.

Today the world is facing three major problems of population increase, pollution and poverty. The developmental efforts of the developing countries, such as India, are being nullified by increasing population and increasing poverty. Although science and technology have improved a lot of large number of human beings some of the worst problems of humanity today such as mentioned above have either been brought about or aggravated by science and technology. Education is one of the most potent instruments in the development process if it is properly geared for that purpose. Science education being an important component of the education system should contribute in the solution of the problems of the country by developing desirable understanding, skills, abilities and attitudes. The greatest challenge is to "humanize" science that is relevant according to the needs of human and aspirations.

The strength of modern economy depends upon the strength of its industry and industrial development in turn depends upon technology that is upon the application of new scientific knowledge, thus all progress grows out of man's creative capacities. It has become essential to train and equip men at every level- research workers, engineers, executives, technicians, office workers and manual workers. Long range planning is no less important. Economists, statisticians and sociologists are the support, now and in the future, of the work of scientists and technicians.

1.2 Historical Context of Science Teaching

Our legacy in science teaching methods can be traced back several centuries to the work of John Amos Comenius (1592-1670) (Cubberley, 1922) a Czech educator, who emphasized that science instruction must move from words to things and the teaching of useful knowledge. Johann Heinrich Pestalozzi (1746-1827) (Cubberley, 1922) a Swiss educator, advocated learning by doing and argued that teaching and learning must be largely analytical. Huxley (1968 [1854]) tends to reduce the anxiety of scientific investigation.

Over the years, methods of teaching science and the curriculums of science have undergone significant changes. Instruction in science has profited from innovative programs such as BSCS, PSSC, ISCS, ESCS, and many other projects with acronyms that are readily recognized. More recently, programs such as the BioQUEST Curriculum Consortium, Project Wild, and case-based learning approach to biological concepts have made problem-solving and decision making inseparable from the content of the discipline. These programs individually and collectively have enlightened science teachers as well as the students at all the levels of instruction.

1.3 Ancient and Medieval Period

India made a pioneer headway in the field of medicine and agriculture till about 600 A.D. The oldest Indian scripture, **Rig Veda**, which was written about 4000 years ago, refers to physicians and speaks about the healing power of medicinal herbs. The concept of atom and the formation of the world as discussed in **The Vaiseshika**, one of the Upanishads, approaches the modern western thought. The Sankhiya philosophy by Kapila is very much like Darwinism. The **Upa- Vedas** or secondary Vedas discuss various sciences. One of these **Upa-vedas** is **Ayur Veda** which consists of six books on surgery, nosology, anatomy, therapeutics, toxicology and supplementary section dealing with various local diseases. Great attention was given to diet. In surgery they attained great proficiency. The ***material medica*** of the hindus embraced a vast collection of drugs belonging to the mineral, vegetable and animal kingdoms many of which have been adopted by western physicians. These were colleges and universities of international repute.

From the point of view of methods and technique of acquiring scientific knowledge, there was considerable development in the refinement of observation. Logical analysis as a tool for refinement of ideas and to arrive at generalizations was also considerably developed. From the point of view of the institutions for acquiring knowledge and continuing the tradition, it may be noticed that they were centered round individuals, who passed on the knowledge and skills to their best disciples only. The result was that most of the scientific knowledge and traditions were lost with time. The early universities of Takshila and Nalanda could be taken as a first step towards institutionalization of teaching and acquiring knowledge but their character must be fully studied, and also the reasons for their disappearance.

In a normal course, the scientific knowledge and the methods and techniques of acquiring it should have led to the next stage of development but this did not happen. The philosophy of Buddhism (Between 750 A.D. to 1000A.D.) discouraged further development of life sciences. Rules of caste became stricter and Brahmins forbade contaminating with blood and withdrew from all practice of medicine. They even shrank from touching dead bodies and as a result of decreasing number of good physicians public hospitals had to be closed. Later, on the gradual conquest of the country by invaders from West Asia and Central Asia brought an element of discontinuity of ancient Indian tradition. The people brought with them different languages i.e. Arabic, Turkish and Persian, and also scientific knowledge, methods, techniques and concepts. There is however some evidence to suggest that many of the scientific ideas brought to India by foreigners during the medieval period had the Indian origin. A large number of scholar went out if India and were patronized at the courts of various feudal

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kings in West Asia and Central Asia. The information, methods, techniques and concepts which they took with them were synthesized and incorporated in the medieval Arabic and Persian scientific traditions of West Asia and Central Asia. This was further developed as a part of the scientific and intellectual developments of these civilizations, the form in which they came to India. There is, however, still a controversy on the origin of many scientific ideas, concepts, methodology and techniques and further studies need to be made before we can fully understand the evolution of scientific thought in medieval India.

1.4 Modern Period

The modern period brings another sharp break in the scientific thought and tradition of India with the conquest of the country by the British. Modern science was introduced in India along with the British, in opposition to the earlier two traditions and again in a foreign language i.e. English. Modern science came to India at a stage of development which marks a radical change from the medieval and ancient sciences, newer branches of sciences had been developed, experimentation developed as a full-fledged technique of acquiring information. Language of science had taken a definite shape, scientific institutions had been developed and technology made a decisive breakthrough.

Modern Science did not make a significance highway in India during the British period for various reasons. Its character was not radically different from the earlier scientific tradition in the country, but the new language made the process of its assimilation in Indian culture difficult. Secondly, it either aroused awe or hostility as a “British thing” alien and hostile to the Indian tradition. The effort, therefore, became once again, one of choice rather than of a synthesis to evolve a scientific tradition in the Indian context.

In order to study the development of science education in India during the modern period we have to look at the history of the Science in the West because whatever happened there was followed in India through a slower pace. At the end of eighteenth century the Universities sadly neglected the teaching of science and it had no place in the school curriculum. Chief scientific discoveries were made by amateurs such as **Cavendish, Priestly, James Watt and Hershel**. A number of philosophical societies were started to fill the gap between the educational provision and the social need, such as Societies of Arts, London, Literary and Philosophical Society of Manchester founded in 1781 and Lunar Society of Birmingham (1766). In 1799, Runford was influential in founding the ***Royal Institute*** of Great Britain. It was intended for teaching young men in the mechanical profession by courses of philosophical lectures and experiments on the application of science to common purpose of life. But later its policy was altogether changed by the influence of Sir Humphry Davy and of Faraday, and this society become the center of research.

The Royal Education Commission reported that in none of the schools science was taught as an independent subject though at Rugby, Natural Science was taught to boys who elected to study it instead of languages. They described it as ‘a plain defect and a great practical evil’. They therefore suggested that Natural Science should be taught and should include two main branches, one comprising physics and chemistry and other Comparative Physiology and Natural History. As a result of this, Physics was introduced in 1837 at Rugby under Dr. Arnold. Dr. Trait, his successor, introduced Botany, Chemistry and Geology in the curriculum in 1859 and a science lecture room and laboratory were built for the first time at the cost of over £1,000.

The great exhibition of 1851 gave further impetus for teaching science in schools, as a result, Department of Science and Art was established in 1853. In 1854, three eminent scientists urged the claims of science as an essential part of general education. **T.H. Huxley** delivered an important address on the Educational value of the Natural History of Sciences. In 1861, **Herbert Spencer** believed that ‘Knowledge of life was the important knowledge for all Moral and Physical.’ The most staunch advocate of teaching science in the ‘sixties’ and ‘seventies’ was **Huxley**. The establishment of natural science course in the Universities of Oxford and Cambridge further paved the way for the inclusion of science in the curriculum of the secondary schools. A full survey of the position of science teaching in secondary schools is contained in the **Devonshire Commission Report** published in 1895.The report begins with the discussion on the difficulties attending the introduction of Science teaching in the schools and recommended that (i) In all public and endower schools a substantial portion of the

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time allotted to-study be devoted to Natural Science, and not less than six hours a week on the average should be assigned for this purpose (ii) school laboratories should be constructed to supply accommodation for practical work in Physics as well as Chemistry in the curriculum of boys schools and of Botany into that of girls school.

Public examinations of Biology and of other science subjects are of very recent origin. Societies of Arts of London held science examination in 1852, designed to qualify for membership. In the course of few years the system became established and papers were set in Botany, Chemistry, Physiology, Mathematics and Mechanics.

Since the beginning of twentieth century there has been an adequate increase in the equipment and facilities for teaching of science in schools. The Great World War of 1914-18 opened the eyes of general public to the importance of general science in the modern world. Sir J.J. Thompson appointed a committee, in 1916, to inquire into the position of Natural Science in the educational system and as a result so named 'Thompson Report' was published under the title 'Natural Science in Education'. As a consequence many advanced courses in science were added to many schools. The Science Masters association and the association of womens science teachers were formed in the early century. School Science Review, the S.M.A. periodical, created a good influence on the teacher as well as public.

1.5 Development of Science Education after Independence

In India, the pattern of education was influenced by what happened in England; the only difference is that things moved at so much slower pace. The reviews issued by Government of India in the years 1877-92 gave an insight into the story state of science teaching. Even in the beginning of this century science was not a school subject in our country and it was only a name in the universities. Indian science congress was formed a few decades back but it also did not do any notable work towards the teaching of science in schools. The Report of the Secondary Education Commission, 1953, recommended the teaching of general science as a compulsory subject in the high and higher secondary schools.

1. All India Seminar on Teaching of Science

The All India Seminar on the teaching of science in secondary schools held at Tara Devi (Shimla Hills) in 1956, dealt with almost all the problems facing the inclusion of general science as a core subject for higher secondary classes. It was the first of its kind which touched almost all the aspects concerning the teaching of science in schools viz. syllabus, equipment and apparatus, method of examination, teaching aids in science and other allied topics like textbooks, Science clubs, Museum etc. It had suggested a unique and uniform system of science teaching for the entire country, suited to its needs and resources.

2. Indian Education Commission (1964-66)

The progress, welfare and security of the nation depend critically on rapid planning and sustainable growth in the quality and extent of education and research in science and technology. Science is universal and so can be its benefits. Science represents a cumulative and cooperative activity of mankind and its rate of growth is extremely rapid. The knowledge of science is doubling in the period of ten to fifteen years.

The commission had pointed out that science education is in bad shape and it becomes worse if we fail to reckon with the explosion of knowledge. To meet this immediate threat, the commission recommended upgrading school curricula by 'research in curriculum development, the revision of the textbooks and teaching learning material.' The commission recommended that:

- Science and Mathematics should be taught on compulsory basis to all pupil as a part of general education during the first ten years of schooling.

- In the lower primary classes teaching should be related to the child environment. The roman alphabets should be taught in class IV to facilitate child's understanding of internationally accepted symbols of scientific measurement and use of maps, charts and statistical tests.
- At the lower secondary stage science should be developed as a discipline of mind. The newer concept of Physics, Chemistry and Biology and the experimental approach to the learning of science should be stressed.
- Science teaching should be linked to agriculture in rural areas and to technology in urban areas.
- Science course as an advanced level may be provided for talented secondary students in selected lower secondary school with facilities of staff and laboratory.
- The method of teaching science should be modernized, stressing the investigatory approach and understanding of the basic principles. Guide materials should be made available to help teachers adopt the approach. Laboratory work will need considerable improvement. There should be flexibility in the curriculum in order to cater to the special needs of the gifted.
- The development of science must derive its nourishment from our cultural and spiritual heritage and not bypass it.
- At the university level, better conditions for research should be provided.

3. National Policy on Education (1968)

The National Policy of Education (1968) marked a significant step in the history of education in post- independence India. It aimed to promote national progress, a sense of common citizenship and culture, and to strengthen national integration. It laid stress on the need for the radical reconstruction of the education system, to improve its quality at all stages, and gave much greater attention to science and technology, the cultivation of moral values and a closer relation between education and the life of the people.

Since the adoption of 1968 policy, there has been considerable expansion in educational facilities all over the country at all the levels. More than 90% of the country's rural habitations now have schooling facilities within a radius of one kilometer.

One of the most significant developments has been the acceptance of a common structure of education throughout the country and the introduction of the 10+2+3 system by most states. In the school curricula, in addition to laying down a common scheme of studies for both boys and girls, science and mathematics were incorporated as compulsory subjects.

4. National Council of Educational Research and Training (NCERT)

The NCERT was established on September 01, 1961 as an autonomous organization with its headquarters in New Delhi. At the headquarters it has National Institute of Education (NIE) which is concerned with research, instruction and evaluation. The NIE functions through its various departments like the department of education in Science and Mathematics, Department of Education in Social Science and Humanities, Department of Educational Psychology, Department of Teacher Education, Department of Textbooks, Department of Teaching Aids National Science Talent Search, Survey and Data Processing and Examination Reform.

A Central Science Workshop was also established under the NCERT to produce prototypes of school equipment and to develop low cost kits for the primary and middle school stages through the various departments of NIE and the Regional Institute of Education, the NCERT discharges functions relating to the improvement of education at all levels of school education and teacher training in India. It also maintains a close liaison with the Education departments and the schools in the different states and the Union territories of India.

Cover Page

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5. State Councils of Educational Research and Training (SCERT) and State Institutes of Science Education (SISE)

Some states have now established State Council of Educational Research and Training (SCERT) on the pattern of NCERT. In these states SCERT incorporates the functions of the States Institutes of Education.

SISEs have been set up in all the states with a view to improve the quality of science education in the schools. The main function of these institutes are to provide in-service training to science teachers in the new developments in the field of science education ; prepare instructional material in the science ; conduct research studies in science education of their respective states; provide guidance service in science to school ; take up innovative programs in science education ; and participate in the national science programs.

6. National Policy on Education 1986

In January 1985, the Government of India announced that a new education policy would be formulated for the country. A comprehensive appraisal of the existing educational scene was made followed by a countrywide debate. The views and the suggestions received from different quarters were carefully studied. As a result new educational policy was established in 1986.

The NPE has reiterated the importance of Mathematics and Science Education as well as inculcation of scientific temper. The committee set up under the chairmanship of Prof. Yash Pal, former Chairman, UGC for implementation of programs for the improvement of the science education has stressed need of proper motivation of teachers in order to enable them to play their role effectively and provision of suitable training to them. To implement this program a detailed scheme for improvement of science education in schools was prepared. The scheme was approved for implementation in 1987-1988. The salient features of the scheme are:

i. Provision of science kits to 90,000 upper primary schools.
ii. Assistance to 22,500 Secondary and Higher Secondary Schools having laboratory rooms and science teachers, to acquire science equipment.
iii. A one-time assistance of ₹ 15000 per Secondary Higher Secondary School each to procure about 500 books relating to Science and Mathematics;
iv. Identification of an educational institution or voluntary agency in each district to act as resource center to help science teachers. Each resource center should be given equipment worth of ₹ 1 lakh.
v. Conducting in-service training in the form of summer institutes in institutions of Higher Education courses in Secondary Teacher Training (College courses in DIETS and through voluntary organizations having expertise.
vi. Assistance on 100% basis to voluntary organizations having expertise to promote scientific temper and science education.

7. National Education Policy 2020

The Union Cabinet approved the new National Education Policy on July 29, after a 34-year gap. The National Education Policy, 2020, is intended to provide a long-term vision and a comprehensive framework for both schools and higher education across the country. The new NEP, approved by the Ministry of Education, proposes to change the school curricular structure from 10+2 to a 5+3+3+4 structure, thereby ensuring curricular continuity in the last four years. A mission for foundational literacy and numeracy

https://www.thehindu.com/education/the-hindu-explains-what-has-the-national-education-policy-2020-proposed/article32249788.ece

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1.6 Basic Conceptual Structure of Biology

It is quite impossible to try to understand the development of any particular concept or a problem in the history of biology until one has answered the questions to him: What is science? What is the place of biology among sciences? And what is the conceptual structure of Biology? To try to answer these questions correctly is my first task of analysis. It is the basis of study for the history of specific concepts.

1.7 Nature of Science

The nature of science can be identified (1) an accumulated and systematized body of knowledge (2) The scientific method of Inquiry, and (3) the scientific attitudes. The first point indicated the PRODUCT of science, while second and third points indicate the PROCESS of science. In other words, science is both a product or a body of knowledge that has been accumulated by scientists, and the process in which they acquire this knowledge.

(a) The body of scientific knowledge: The body of scientific knowledge can be classified into facts, concepts and generalizations, theories and laws. These form the structure of science.
(b) The process of science: The second dimension of science is the process by which the knowledge is acquired. In an attempt to define processes of science, the American Association for the Advancement of Science (AAAS) asked scientists to say what they actually do. The following list of thirteen process came from this enquiry.
    (1) Observation, (2) Classification, (3) Number relations, (4) Measurement, (5) Space/time relations, (6) Communication, (7) Prediction, (8) Inference, (9) Making operational definitions, (10) Formulating Hypothesis (11) Interpreting data (12) Identifying and controlling variables, (13) Experimenting.

Since the early 2000s, Biology Education Research (BER) has emerged as a formal research field distinct from traditional teaching practices: BER focuses on systematic, evidence-based study of how students learn biology and how instructional practices affect learning outcomes. Journals such as CBE: Life Sciences Education were established in 2002 to publish peer-reviewed work on instructional interventions, assessment of student understanding, and evidence for improved teaching practice. A review of science education research from 1990–2010 found a majority of biology learning studies were published after 2000, indicating rapid growth in research into student learning and instructional efficacy.

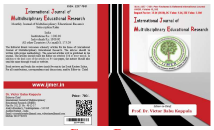
Across global contexts, many reforms since 2000 highlight inquiry-based and student-centered learning: In contexts such as China, biology curricula shifted after 2000 from content memorization toward inquiry and skills-based learning, demanding changes in both curricula and teacher preparation. Recent education research explores design-based and integrated STEM approaches that combine biology with engineering and other sciences to deepen conceptual understanding.

A meta-analysis of conceptual change interventions (i.e., studies that help students restructure their understanding of biological ideas) shows that: Topics like evolution and photosynthesis are among the most studied in research aiming to support deep conceptual understanding. This body of work highlights persistent misconceptions and the effectiveness of instructional strategies that target underlying ideas rather than rote memorization.

1.8 The Structure of Science

The structure of science can be compare to the framework of a building under construction. A framework of building consists of foundation, vertical pillars and horizontal beams to the methods are process of science. The facts are comparable to the building materials i.e. stone, bricks and concrete etc. In this analogy the vertical pillars and the horizontal beams of science is subject to alteration on the basis of empirical tests. It should be noted that this analogy of building under construction is to facilitate understanding of the structure of science.

It may be worthwhile to know the differences between facts, concepts, generalizations, theories and laws because these terms are commonly used in science.



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1. Facts

Facts are all the basis of all knowledge. They are said to be grassroots for any theory or law.

Since science is the human enterprise, it has its limitations, because science does not merely involve recording and classifying facts, but also involves speculation, intuition, and imagination. This quality of science makes it subject to errors. Scientists not only make mistakes in their observation but also make errors in formulating models or theories. The facts, models, or theories which are proved wrong in the course of time are discarded and replaced by new ones. *The whole process of the scientific enterprise is continuously replenished by new facts and discoveries.* The process of acquiring scientific information can be compared to a building.

2. Concepts

A concept is a generalized idea suggested to the individual by object, symbol or situation, It is not synonym for principle. It is rather an understanding of almost indefinable something. For example: the concept of dog for a three year old child is different from ten-years or twelve years old child. So the concepts about different objectives and phenomena are different for different people according to their age and experience.

Examples:

a) **Development** is the product of 'Heredity and Environment'.
b) The **mass** of a body is equal to the product of its density and volume.

3. Generalisation

Generalisations are very helpful in deriving useful conclusions regarding the 'scientific facts'. Actually the facts, concepts and generalisations are inter-related and inter-dependent. The facts give rise to concepts and when the facts and concepts are properly classified on the basis of various scientific process, they give rise to generalisations. It is not essential that only direct experiences should be used in making generalisations. Many times our generalisations are based on indirect experiences such as listening the same thing from a number of sources. However, in the field of sciences, we usually take help of direct experiences in the form of self –observation and experimentation for deriving valid generalisations.

Example:

Let us take another case of generalization 'All bodies are attracted by earth'. When a child throws a piece of chalk upwards, it falls down on earth. When he tries the similar experiment with the help of piece of stone, he observes the same phenomenon. After that, the child performs similar activity with the help of a glass ball, a pencil, a book and finds the same results. Hence he draws the conclusion that **all substances when thrown upwards, fall on the earth**. Therefore, the child generalizes that all bodies are attracted by earth.

4. Theory

Theory constitutes a fundamental tool of scientific inquiry, serving as the intellectual structure through which facts are organized, interpreted, and explained. Scientific knowledge advances not merely through the accumulation of empirical observations, but through the formulation of theories that integrate these observations into coherent explanatory systems. In this sense, theory provides both meaning and direction to scientific investigation.

Kerlinger defines theory as "a set of interrelated concepts, definitions, and propositions that present a systematic view of phenomena by specifying relations among variables with the purpose of explaining and predicting phenomena." This

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definition highlights the structured and relational nature of theory, emphasizing its dual role in explanation and prediction. Similarly, Good and Hatt view theory as the meaningful ordering of facts, suggesting that theory transforms isolated data into an intelligible pattern. Matheson further emphasizes the predictive function of theory by defining it as a specification of relationships between events for the purpose of explaining their occurrence and forecasting future events.

Together, these definitions underscore that scientific theory is not a speculative construct but a systematically developed explanatory framework grounded in empirical evidence.

Functions of Theory in Scientific Research

In scientific research, theory performs several critical functions. First, it provides a conceptual framework that identifies relevant variables and specifies their interrelationships. This framework enables researchers to move beyond descriptive studies toward explanatory and analytical inquiry. Second, theory offers explanatory power, allowing researchers to account for observed regularities and causal mechanisms underlying phenomena. Third, theory facilitates prediction, enabling researchers to anticipate outcomes under specific conditions and thereby test the validity of theoretical propositions. Finally, theory guides the formulation of hypotheses and the selection of appropriate research methods, ensuring systematic and focused investigation.Functions of Theory in Scientific Research In scientific research, theory performs several critical functions. First, it provides a conceptual framework that identifies relevant variables and specifies their interrelationships. This framework enables researchers to move beyond descriptive studies toward explanatory and analytical inquiry. Second, theory offers explanatory power, allowing researchers to account for observed regularities and causal mechanisms underlying phenomena. Third, theory facilitates prediction, enabling researchers to anticipate outcomes under specific conditions and thereby test the validity of theoretical propositions. Finally, theory guides the formulation of hypotheses and the selection of appropriate research methods, ensuring systematic and focused investigation.

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