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# Interdisciplinarity in Modern Science: Methodological Aspects

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**Abstract:** The article is devoted to methodological aspects of interdisciplinarity in modern science. The essence of the interdisciplinary approach and its difference from related forms of knowledge integration are considered. The historical background and key characteristics of interdisciplinary research are analyzed. Special attention is paid to methodological issues, including terminological barriers, differences in standards and organizational difficulties. Examples of successful interdisciplinary projects such as genome sequencing and artificial intelligence research are given. The advantages of interdisciplinarity, including innovative potential and integrated solutions to global problems, are discussed. There are also challenges related to the academic tradition and the assessment of the quality of research. The article highlights the need to develop a methodological culture of interdisciplinary work.

**Keywords**: global problems; integration; interdisciplinarity; modern science; knowledge

## 1. Introduction

Modern science is going through a period of unprecedented specialization, accompanied by the simultaneous blurring of boundaries between traditional disciplines. This paradox is explained by the increasing complexity of scientific problems that require the integration of knowledge from various fields. The relevance of interdisciplinary approaches research is due to their key role in the most

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significant scientific breakthroughs of recent decades, from decoding the human genome to the development of artificial intelligence. The purpose of the article is to analyze the methodological foundations of interdisciplinarity as a systemic phenomenon of modern science. Modern science is also experiencing an era of unprecedented knowledge growth: the volume of published research doubles every 9-15 years, and the number of new disciplines and specializations increases exponentially. The most significant breakthroughs of recent decades have occurred not within the framework of traditional sciences, but at their junctures, thanks to the integration of methods and concepts from different fields. Interdisciplinarity is becoming not just a trend, but a prerequisite for solving complex global problems, from climate change to the creation of artificial intelligence.

➢ The information explosion and the limitations of a highly specialized approach

The 21st century is characterized by a crisis of hyper-specialization: even within a single discipline, a scientist cannot cover all the published data. For example, over 1 million articles appear in biomedicine annually, and about 500 thousand in physics. At the same time, many fundamental issues require a synthesis of knowledge:

- brain research is impossible without combining neuroscience, computer modeling, psychology and even philosophy of consciousness;
- the development of new materials depends on the cooperation of chemists, physicists, engineers and machine learning specialists. Highly specialized approaches often lead to "tunnel thinking", when the solution to a problem in one area ignores the consequences in another. For example, the introduction of pesticides in agronomy in the 1950s was initially considered a success, but later required the intervention of environmentalists and toxicologists to assess long-term risks.

➢ Specific examples of interdisciplinary breakthroughs.

- Decoding the human genome (2003)

The Human Genome project became possible only through the integration of biology (DNA decoding), computer science (big data processing algorithms), mathematics (statistical analysis), and Engineering (next-generation sequencers). As a result of this breakthrough, personalized medicine and gene therapy have emerged.

The Human Genome project (1990-2003) has become one of the most ambitious scientific achievements possible only through the integration of four key disciplines: biology, computer science, mathematics and engineering. This project not only deciphered the DNA sequence, but also created new scientific fields such as bioinformatics and revolutionized medicine.

- Biology: deciphering the structure of DNA

Another breakthrough has been achieved in biology due to interdisciplinary connections. The task was to determine the exact sequence of the 3.2 billion pairs of nucleotides that make up the human genome.

The task was completed thanks to Sanger sequencing (the first generation), which is based on the enzymatic synthesis of DNA with terminators. This made it possible to "read" up to 500-800 pairs of nucleotides in one run. New methods have also appeared: PCR (polymerase chain reaction) and multiplication of DNA fragments for analysis. Previously, the task was not solved using traditional methods and the research was too slow for the genome scale.

➢ Computer Science: Big data processing

- Computer science had an equally ambitious task: to systematize and analyze huge amounts of genetic information.

To do this, new genome assembly algorithms have emerged within the framework of computer science. DNA fragments (read by sequencers) had to be "stitched" into a single sequence. And for this, graph algorithms were used (for example, the de Bruijn algorithm). Accordingly, data storage volumes have increased significantly, exceeding 200 TB. Specialized databases (GenBank, UCSC Genome Browser) began to be developed. For example, the BLAST (Basic Local Alignment Search Tool) program made it possible to compare DNA sequences with already known genes.

➢ Mathematics: statistical analysis and modeling

Mathematicians have set the task to identify significant sections of DNA (genes, regulatory zones) among the "junk" DNA. And this problem has been solved through interdisciplinary methods:

- statistics and probability theory;
- definition of polymorphisms (SNP – single nucleotide polymorphisms);
- calculation of correlations between genes and diseases;
- machine learning;
- predicting the functions of genes based on their structure.

As a result, hidden Markov model (HMM) methods helped predict genes in unannoted DNA regions.

➢ Engineering: new generation sequencers

Scientists have set a goal: to speed up and reduce the cost of sequencing. As a result of the interdisciplinary approach, the following technological breakthroughs have been achieved:

- high-throughput sequencing (NGS);
- Illumina, PacBio: allow parallel analysis of millions of DNA fragments;
- cost reduction from $100 million (2001) to $600 (2023) per genome;
- nanotechnology in sequencing;
- Oxford Nanopore: real-time sequencing via nanopores.

As a result, without engineering solutions on an interdisciplinary basis, the project would have taken decades instead of 13 years.

➢ Interdisciplinary synthesis and implications

As a result of this interdisciplinary synthesis, new branches of knowledge have emerged such as:

- bioinformatics is a new science at the intersection of biology and programming;
- personalized medicine – treatment based on an individual genome;
- CRISPR-Cas9 is a gene editing technology that arose from understanding the structure of DNA.

To summarize, we emphasize that: decoding the human genome is a vivid example of how an interdisciplinary approach overcomes the limitations of individual sciences. Today, projects such as UK Biobank or All of Us continue this tradition, combining genetics, big data and AI for new discoveries.

➢ Artificial intelligence and neuroscience

Modern AI is a product of the interaction of a number of related disciplines: computer science (deep learning algorithms), cognitive psychology (thinking modeling), and neuroscience (the study of brain function).

An example that led to new discoveries: neural networks that mimic the visual cortex (DeepMind, 2010s), or hybrid brain-computer interfaces, have appeared.

➢ Climate research

Forecasting climate change requires collaboration between physics (atmospheric models), chemistry (greenhouse gas analysis), economics (social impact assessment), and political science (development of international agreements). Without such a synthesis, the IPCC reports or the Paris Agreement (2015) would not have been possible.

➢ Challenges requiring interdisciplinary solutions

The global problems of the 21st century – pandemics, the energy transition, and population aging – cannot be solved within the framework of science alone:

- COVID-19 has been studied by virologists, epidemiologists, mathematicians (spread models), sociologists (human behavior), and IT specialists (contact tracking);
- the development of quantum computers unites physicists, engineers, programmers and even cryptographers.

Modern science has reached the "limits of specialization" – further progress depends on the ability of researchers to go beyond the boundaries of disciplines. Interdisciplinarity is no longer an option and is becoming a strategic necessity, which is confirmed by all the major discoveries of recent years. Studying its methodological aspects is the key to accelerating innovation and overcoming global crises.

➢ The concept and essence of interdisciplinarity. Theoretical foundations

Interdisciplinarity should be distinguished from related concepts:

- multidisciplinary – a simple neighborhood of disciplines without integration;
- transdisciplinarity – going beyond academic knowledge.

The key criterion of interdisciplinarity is the emergence of a synergetic effect when integrating methods and concepts from various sciences. As Nicolescu (Nicolescu, 2002) notes, this leads to the formation of new epistemological paradigms.

➢ Historical evolution

The origins of the interdisciplinary approach can be traced:

- in the ancient tradition (Aristotle as an encyclopedist);
- in the Age of Enlightenment (Diderot and the concept of "universal knowledge");
- in the 20th century (Wiener cybernetics as a "bridge" between technical and humanitarian sciences).

The modern stage (since the beginning of the 21st century) is characterized by the institutionalization of interdisciplinarity through the creation of specialized research centers.

- ➢ Methodological aspects of interdisciplinary research. The specifics of the methods

Interdisciplinary research of the modern period is characterized by the use of combined qualitative and quantitative approaches, the use of "borrowed" methods (for example, mathematical modeling in biology), as well as the use of systems analysis as an integrative methodology.

- ➢ Epistemological challenges

The main problems of the interdisciplinary approach include:

- terminological barriers between disciplines;
- differences in the criteria of evidence;
- incompatibility of research paradigms.

As Klein's (Klein, 2010) research shows, successful interdisciplinary projects require the development of a "common language."

- ➢ Organizational arrangements

Effective interdisciplinary work involves a number of activities such as:

- creation of flexible organizational structures (laboratories, consortia);
- development of new forms of scientific communication;
- modification of the results assessment system.

An example of the result of such efforts by scientists was the creation of the MIT Media Lab as a model of an interdisciplinary institute.

- ➢ Practical implementation: interdisciplinary research cases.
  - Genomic research

The Human Genome project (2003) could have been solved by combining molecular biology, computer science, and mathematical modeling. The result of this work was the emergence of a new discipline – bioinformatics.

- Cognitive Sciences

Consciousness research required the integration of the following types of knowledge: Neuroscience, Psychology, Philosophy, Artificial intelligence.

- Climate research

Climate change modeling is based on: Atmospheric Physics, Chemistry, Economy, Political Science.

- Problems and prospects of interdisciplinarity. Institutional barriers

We include such barriers: conservatism of the academic system, difficulties in evaluating interdisciplinary publications, financing problems.

Among promising areas we can mention: development of Converged Technologies (NBIC); formation of new educational standards and Creation of interdisciplinary research platforms.

## Conclusion

This article demonstrates that interdisciplinarity has ceased to be an auxiliary methodological tool and has become an independent paradigm of scientific knowledge. This is confirmed by three fundamental conclusions: A clear distinction between interdisciplinarity, multidisciplinarity and transdisciplinarity has allowed us to highlight its unique feature – the synergy of integration, when the interaction of disciplines generates qualitatively new knowledge. A historical analysis has shown that the evolution of science has always moved towards blurring the boundaries between disciplines, but only in the 21st century this process became systematic.

Interdisciplinary research requires specific methods: from borrowing algorithms (as in bioinformatics) to creating new forms of scientific communication.

The main challenges in this research are terminological barriers and institutional rigidity, which are overcome through the formation of a "common language" and flexible organizational structures (for example, the MIT Media Lab).

What is the practical significance of the research?

The cases (Human Genome, AI, climate models) proved that the most breakthrough discoveries of the last 20 years have been made at the intersection of disciplines. These successes have led to the emergence of new scientific fields: bioengineering, neuroeconomics, and digital humanities.

Modern science is faced with the "limits of specialization": narrow disciplinary frameworks no longer allow us to solve complex problems such as climate change, population aging or pandemics. Interdisciplinarity offers an alternative in this regard:

- an epistemological shift: From the "separate" study of phenomena to their systematic modeling (for example, brain research now combines neuroscience, physics, computer modeling, and even philosophy of mind);

- new criteria of truth: in interdisciplinary projects, traditional criteria (for example, reproducibility in physics) are complemented by convergence of evidence from different fields.

Undoubtedly, this implies a change in the role of the scientist: the researcher must now be not only a specialist, but also a "translator" between disciplines.

Gene editing technology was born at the junction of microbiology (the study of bacterial immunity), biochemistry (the study of enzymes), computer science (DNA sequence analysis), ethics (assessment of the consequences of application).

➢ What to expect in the near future? Technological trends:
- convergent Technologies (NBIC): Nanotechnology, biotechnology, information technology and cognitive sciences will merge into a single field (an example is neural interfaces like Neuralink);
- AI as an "integrator": Machine learning algorithms (for example, AlphaFold for predicting protein structure) will become a bridge between disciplines.

Undoubtedly, this will affect organizational changes:

- new network research centers will appear (instead of traditional departments, temporary interdisciplinary teams, as in the European Human Brain Project);
- education reform: the emergence of Bio-X programs (Stanford), where students simultaneously study biology, engineering, and computer science. Methodological innovations: the emergence of hybrid methods, when quantum computing and molecular modeling are combined in drug development.

How will this affect civil science? More often than not, non-specialists will be involved (through crowdsourcing) in data collection and analysis, as in the Foldit project (game prediction of protein structure).

However, this process may have challenges and risks: manifested by a loss of depth, there is a risk of superficial research with insufficient expertise in certain areas.

The emergence of an ethical dilemma (as has happened, for example, in genetics and AI) will require new interdisciplinary regulatory standards.

Interdisciplinarity is not just a method, but a new logic of scientific knowledge that meets the challenges of the complexity of the modern world.

Its development in the next decade will determine the leaders of the scientific and technological race: countries and institutions capable of creating effective integration mechanisms.

The key issue of the future is the balance between specialization and interdisciplinarity. The solution may lie in the "T-shaped" model of a scientist: deep expertise in one field and a broad interdisciplinary outlook.

The final conclusion is that the science of the future will be based not on disciplines, but on problem-oriented approaches, where interdisciplinarity will become the rule, not the exception. This transition has already begun, and its pace will only accelerate.

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