Research Methodology for Pursuing Research in Engineering-1

KR Chowdhary
Former Professor & Head

Dept. of CSE, MBM Engineering College, Jodhpur
Email: kr.chowdhary@acm.org
Web: http://www.krchowdhary.com

November 25, 2024

Meaning of Research

- Research in common parlance refers to a search for knowledge.
- According to *Clifford Woody* research comprises defining and redefining problems, formulating hypothesis[1] or suggested solutions;
- Research is, thus, an original contribution to the existing stock of knowledge making for its advancement.
- As such the term "research" refers to the systematic method consisting of enunciating the problem, formulating a hypothesis, collecting the facts or data, analyzing the facts and reaching certain conclusions.

[1] a supposition or proposed explanation made on the basis of limited evidence as a starting point for further investigation.

Research Objectives

- To gain familiarity with a phenomenon or to achieve new insights into it (exploratory or formulative research),
- To portray accurately the characteristics of a particular individual, situation, or a group studies (descriptive research),
- To test a hypothesis of a **causal** relationship between variables (hypothesis-testing research studies).

Types of Research

- Descriptive vs. Analytical: The first includes surveys and fact-finding inquiries of different kinds, major purpose is: description of the state of affairs as it exists at present. Analytical: The researcher has to use facts or information already available, and analyze these to make a critical evaluation of the material.
- Gathering knowledge for knowledge's sake is termed 'pure' or basic research.
- Applied vs. Fundamental: Research can either be applied (or action) research or fundamental (to basic or pure) research. Applied research aims at finding a solution for an immediate problem facing a society or industrial/business organization. Fundamental Research.: mainly concerned with generalizations and with the formulation of a theory.

Research and Scientific Method

- The two terms, "research" and "scientific method", are closely related. Research is "an inquiry into the nature of, the reasons for, and the consequences of any particular set of circumstances, whether these circumstances are experimentally controlled or recorded just as they occur."
- *Karl Pearson* writes, The "scientific method" is one and same in the branches (of science) and is the method of all logically trained minds ... the unity of all sciences consists alone in its methods,
- "Experimentation" is done to test hypotheses, and to discover new relationships, if any, among variables.

Basic postulates[3] of the scientific method:

- It relies on *empirical evidence*[2];
- It utilizes relevant concepts;
- It is committed to only objective considerations;
- It presupposes ethical neutrality, i.e., it aims at nothing but making only adequate and correct statements;
- It results into probabilistic predictions;
- Its methodology is made known to all concerned for critical scrutiny are for use in testing the conclusions through replication;
- It aims at formulating most general axioms or what can be termed as scientific theories.

---

[2]Empirical evidence: Information gathered directly or indirectly through observation or experimentation

[3]a statement that is believed or accepted to be true, that forms the basis of a theory, etc.

Importance of Knowing Research Process

The study of research methodology gives us necessary training in gathering material and arranging or indexing them,

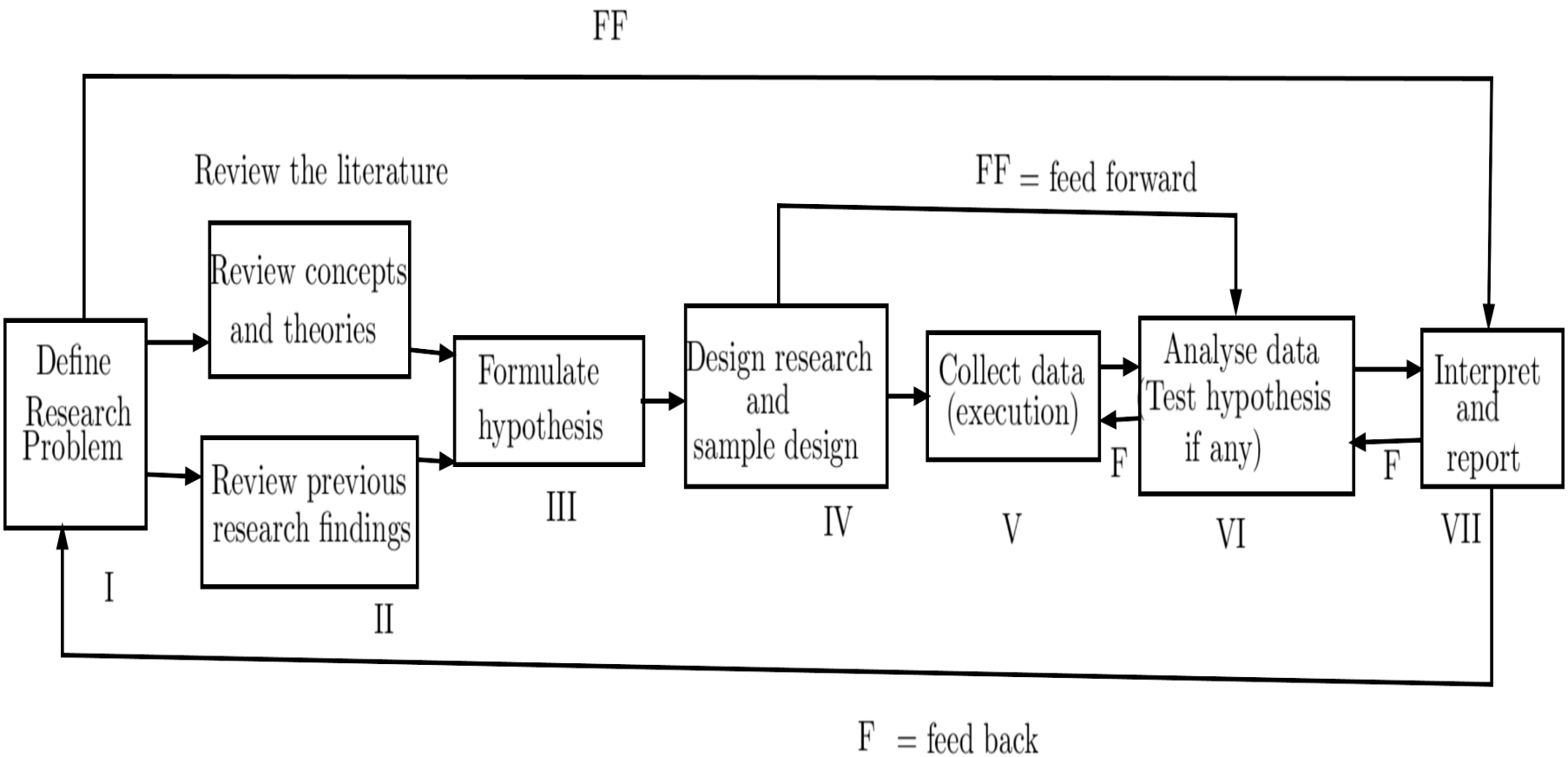
- Knowing *research methodology* and *research techniques* is obvious since the same constitute the tools of his/her work.
- Knowledge of how to do research will inculcate the ability to evaluate and use research results with reasonable confidence.
- When one knows how research is done, then one may have the satisfaction of acquiring a new intellectual tool which can become a way of looking at the world,
- In scientific age, all of us are in many ways consumers of research results and we can use them intelligently provided we are able to judge the adequacy of the methods.

General Questions

1. What is meaning of "formulating hypothesis"?
2. What is a scientific method?
3. What are the rules (postulates) of scientific method?
4. What are the different types of research in following?
   - 4.1 Pre-poll and post poll surveys,
   - 4.2 data collection of families to reporting,
   - 4.3 data collection of education and monthly income to establish the relation between education vs. earnings,
   - 4.4 to determine the living standards of people in Rajasthan based on data available,
   - 4.5 to determine the relation between value of "pi, dia, and circumference" of a circle,
   - 4.6 to calculate energy produced per fission in uranium.
   - 4.7 To predict the sales in Amazon using AI
   - 4.8 To determine which is most effective learning method to be applied so that power required generation in a power plant can be predicted correctly, in advance? (Out of reinforcement learning, supervised learning, unsupervised learning)?

Research Process

Before we proceed on details of research methodology and techniques, here is brief overview of research process. It consists of series of actions or steps necessary to effectively carry out research and the desired sequencing of these steps (see Figure↓).



Research Process..

The research process consists of a number of closely related activities, as shown through I to VII.

I. formulating the research problem; (see examples)

ii. extensive literature survey;

iii. developing the hypothesis;

iv a. preparing the research design;

iv b. determining sample design;

v a. collecting the data;

v b. execution of the project;

vi a. analysis of data;

vi b. hypothesis testing;

vii a. generalizations and interpretation, and

vii b. preparation of the report or presentation of the results, i.e., formal write-up of conclusions reached.

I. Formulating the research problem

- There are two types of research problems, viz., 1. it relate to states of nature, 2. it relate to relationships between variables.
- Initially the problem may be stated in a broad general way, later, ambiguities, if any, be resolved. next, the feasibility of a particular solution has to be considered,
- The best way to understand the problem: discuss it with colleagues or those having some expertise in the subject.
- The researcher must examine all available literature to get him/herself acquainted with the selected problem.
- Formulate the problem..

Some examples of formulating research problems

- Apply machine learning techniques to signal processing problems, such as image and speech recognition.
- Investigate advanced control strategies for efficient integration of renewable energy sources into smart grids
- Investigate novel materials and devices for optical communication and signal processing.
- Investigate methods for enhancing the stability and reliability of power systems.
- Investigating applications autonomous vehicles, and industrial automation in smart cities,
- Develop advanced machine learning algorithms for complex pattern recognition.
- Investigating the explainability and interpretability of deep learning models.

Some results of formulating research problems...

-Explore novel techniques for sentiment analysis and emotion recognition in text.
-Develop advanced NLP models for understanding context and discourse.
-Investigate methods for robust object detection and tracking in real-world scenarios.
-Develop advanced control algorithms for robotic systems.
-Investigate human-robot collaboration and swarm robotics for industrial applications.
-Explore advanced computational fluid dynamics (CFD) for complex flow simulations.
-Investigate advanced structural materials for high-performance applications.
-Explore methods for vibration control and damping in mechanical
systems.
-Explore strategies for designing & activating public spaces to enhance social interaction and community engageme

II. Extensive literature survey

- Once the problem is formulated, a brief summary of it should be written down.
- It is compulsory for a research worker writing a thesis for a Ph.D. degree to write a synopsis of the topic and submit it to the necessary Committee or the Research Board for approval.
- At this juncture the researcher should undertake extensive literature survey connected with the problem.
- In this process, it should be remembered that one source will lead to another.
- Resources: books, conference, journals, social media, ..

III. Development of working hypotheses

State in clear terms the working hypothesis. It is a tentative assumption made in order to draw out and test its logical or empirical consequences.

How to develop working hypothesis?

- Discussion with colleagues and experts about the problem, its origin and the objectives in seeking a solution;
- Examining data and records, if available, concerning the problem for possible trends, peculiarities and other clues;
- Review of similar studies in the area,
- Exploratory personal investigation which involves original field interviews.

Thus, working hypotheses arise as a result of *a-priori* thinking about the subject, examination of the available data and material. (In what situations you do not need working hypothesis?)

Example of a working hypothesis for Electrical Engineering

Hypothesis: "The integration of machine learning algorithms into power distribution systems can significantly enhance the efficiency and reliability of smart grids by optimizing energy flow, predicting faults, and adapting to dynamic demand patterns."
Explanation: In this hypothesis, the researcher proposes that incorporating machine learning algorithms into power distribution systems has the potential to bring about improvements in various aspects, such as optimizing energy distribution, predicting and preventing faults, and adapting to changes in demand. The hypothesis suggests that the application of advanced computational techniques can lead to a more intelligent and efficient electrical grid.

The researcher would then design experiments, simulations, or data analyses to test and validate this hypothesis throughout the course of their PhD research. The findings would contribute to the understanding of the feasibility and effectiveness of integrating machine learning into power distribution systems, providing insights for future developments in smart grid technology.

Examples of a working hypothesis for Mechanical

Hypothesis: "The utilization of advanced composite materials with tailored microstructures in the design of turbine blades will result in a significant improvement in fatigue resistance, leading to extended operational lifespan and enhanced performance in gas turbine engines."
Explanation: In this hypothesis, the researcher is putting forward that, by employing advanced composite materials with specific micro-structural characteristics, the fatigue resistance of turbine blades can be notably increased. The expected outcome is that this enhancement will contribute to a longer operational lifespan for gas turbine engines and, concurrently, an improvement in overall performance.

To test this hypothesis, the researcher might conduct experiments involving the fabrication and testing of turbine blades made from these advanced composite materials. They would analyze factors such as fatigue strength, micro-structural integrity, and overall performance compared to traditional materials. The findings would contribute to the understanding of the potential benefits of using advanced composites in gas turbine applications and could have implications for the design and manufacturing of aerospace components.

Examples of a working hypothesis for Computer Science

Hypothesis: "Developing a novel deep learning architecture based on attention mechanisms for natural language processing tasks will yield superior performance in understanding and generating contextually rich and coherent text, surpassing the capabilities of existing state-of-the-art models."
Explanation: In this hypothesis, the researcher suggests that the incorporation of attention mechanisms into a deep learning architecture specifically designed for natural language processing tasks will lead to better performance compared to currently established models. The hypothesis focuses on the goal of achieving a deeper understanding and improved generation of contextually relevant and coherent textual information.

To test this hypothesis, the researcher would likely design and implement the proposed deep learning architecture, conduct experiments using relevant datasets and benchmarks, and then evaluate the model's performance in comparison to existing state-of-the-art models. Metrics such as accuracy, language coherence, and efficiency would be analyzed to determine whether the novel architecture indeed outperforms existing approaches in natural language processing.

The findings from this research would contribute to advancements in the field of deep learning for natural language processing, potentially leading to more effective models for tasks such as language understanding, translation, and text generation.

Examples of a hypothesis for Architecture and town planning

Hypothesis: "The integration of green infrastructure, such as urban parks, green roofs, and sustainable landscaping, into urban development projects leads to measurable improvements in environmental sustainability, community well-being, and overall urban resilience."
Explanation: In this hypothesis, the researcher suggests that incorporating green infrastructure elements into urban planning and architectural design can have positive effects on multiple dimensions of urban life. The hypothesis focuses on environmental sustainability, community well-being, and urban resilience as key areas of potential improvement.

To test this hypothesis, the researcher might conduct a comprehensive study involving the implementation of green infrastructure in selected urban areas. The study could include the analysis of environmental indicators (e.g., air and water quality, biodiversity), community surveys to assess well-being, and evaluations of the area's resilience to factors such as extreme weather events.

The outcomes of this research could provide evidence on the effectiveness of integrating green infrastructure in urban planning, offering practical insights for architects, planners, and policymakers aiming to create more sustainable and resilient cities with enhanced quality of life for residents.

IV a. Preparing the research design

- Having formulated the research problem in clear cut terms, you need to prepare a research design,
- The function of research design is to provide for the collection of relevant evidence with minimal expenditure of effort,
- Several research designs possible, such as, experimental and non-experimental hypothesis testing.
  Involves usually the consideration of the following:
  - the means of obtaining the information;
  - the availability and skills of the researcher and his staff
  - explanation of the way in which selected means of obtaining information
  - the time available for research; and
  - the cost factor relating to research,

IV b. Determining sample design (often for surveys only)

- All the items under consideration in any field of inquiry constitute a "universe" or "population".
- The researcher must decide the way of selecting a sample or what is popularly known as the sample design.
  Some sample designs are as follows:
  - Deliberate sampling
  - Simple random sampling
  - Systematic sampling
  - Stratified sampling
  - Quota sampling
  - Cluster or area sampling
  - Multi-stage sampling
  - Sequential sampling

  The sample design must be decided considering nature of the inquiry.

V a. Collecting the data

In dealing with any real life problem it is often found that data at hand are inadequate, and hence, it becomes necessary to collect data that are appropriate. In the case of a survey, data can be collected by any one or more of the following ways:

- By observation
- Through personal interview
- Through telephone interviews
- By mailing of questionnaires
- Through schedules

In experimental research data is collected through conducting experiments.

V b. Execution of the project

- If the execution of the project proceeds on correct lines, the data to be collected would be adequate and dependable.
- If the survey is to be conducted by means of structured questionnaires, data can be readily machine-processed.
- If the data are to be collected through interviewers, arrangements should be made for proper selection and training of the interviewers.
- Keep the survey as much realistic as possible.
- Ensure that the survey is under statistical control so that the collected information is in accordance with the pre-defined standard of accuracy.

VI a. Analysis of data

- The analysis of data requires a number of closely related operations such as establishment of categories, the application of these categories to raw data through coding, tabulation and then drawing statistical inferences.
- A great deal of data, specially in large inquiries, is tabulated by computers.
- In the process of analysis, relationships or differences supporting or conflicting with original or new hypotheses should be subjected to tests of significance

VI b. Hypothesis-testing

- After analyzing the data, the researcher is in a position to test the hypotheses, if any, has been formulated.
- Do the facts support the hypotheses or they happen to be contrary?
- Various tests, such as Chi square test, t-test, F-test, have been developed for the purpose.
- The hypotheses may be tested through the use of one or more of such tests, depending upon the nature and object of research inquiry.
- Hypothesis-testing will result in either accepting the hypothesis or in rejecting it.
- If the researcher had no hypotheses to start with, generalizations established on the basis of data may be used as hypotheses by other researches.

(χ) Chi Square test

It is a non-parametric statistical test that is used to determine whether there is a significant association between categorical variables.
Here are the basic steps involved in performing a Chi-square test:
1. *Formulate Hypotheses*: Null Hypothesis (H0): Assumes that there is no association between the variables. Alternative Hypothesis (H1):Assumes that there is a significant association between the variables.
2. *Collect and Organize Data*: Arrange the data in a contingency table, where rows represent one variable, and columns represent the other variable.
3. *Calculate Expected Frequencies (E_i)*: Determine the expected frequency for each cell i in the contingency table under the assumption of independence between the variables.
4. *Calculate χ-square Statistic*: Compute the Chi-square statistic using the formula:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

where O_i is the observed frequency in cell i, and E_i is the expected frequency in cell i.

The Chi-square test is commonly used in social sciences, and business, to analyze relationships between categorical variables.

V a. Generalizations and interpretation

- If a hypothesis is tested and upheld several times, it may be possible for the researcher to arrive at generalization, i.e., to build a theory.
- As a matter of fact, the real value of research lies in its ability to arrive at certain generalizations.
- If the researcher had no hypothesis to start with, he/she might seek to explain his/her findings on the basis of some theory.
- It is known as interpretation. The process of interpretation may quite often trigger off new questions which in turn may lead to further researches.

VII b. Preparation of the report or the thesis

Finally, the researcher has to prepare the report of what has been done by him/her. Writing of report must be done with great care keeping in view the following:
The layout of the report should be as follows:

-the preliminary pages;
-the main text, and
-the end matter.

In its preliminary pages the report should carry title and date followed by acknowledgments and foreword. Then there should be a table of contents followed by a list of tables and list of graphs and charts, if any, given in the report.

Thesis/Report..

The main text of the report should have the following parts:

1. Introduction
2. Summary of findings
3. Main report
4. Conclusion

Preparation of the report or the thesis ...

- At the end of the report, appendices should be enlisted in respect of all technical data. Bibliography, i.e., list of books, journals, reports, etc.,
- Report should be written in a concise and objective style in simple language avoiding vague expressions such as “it seems,” “there may be”, and the like.
- Charts and illustrations in the main report should be used only if they present the information
- Calculated “confidence limits”