Dr. Norbert Cheung's Lecture Series

Level 5 Topic no: 34

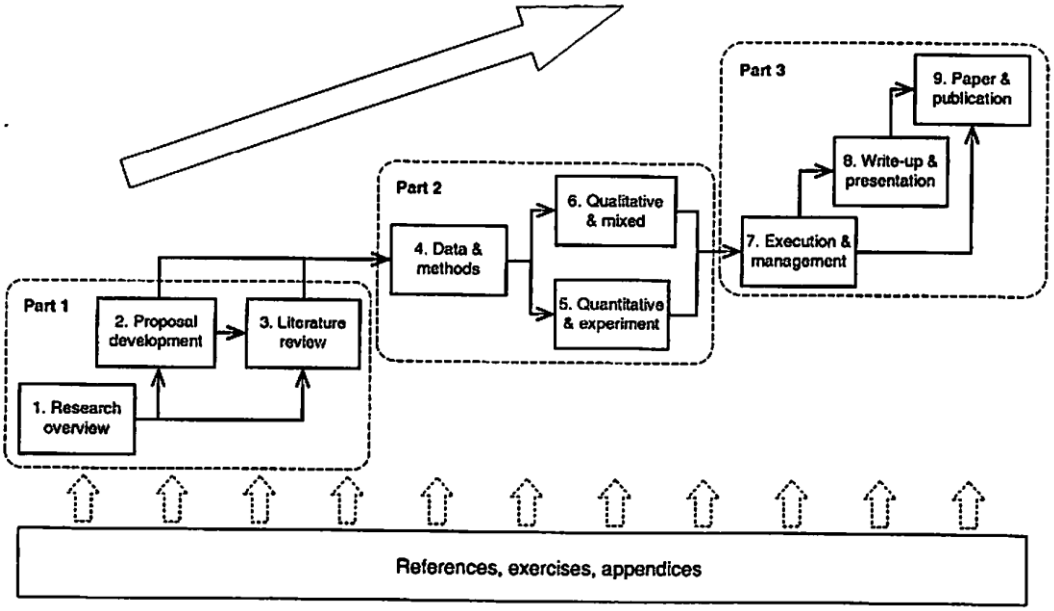
Research Overview

Contents

Reference

Engineering Research: Design Methods and Publication, Herman Tang, Wiley, 2021.

1. What is Research?

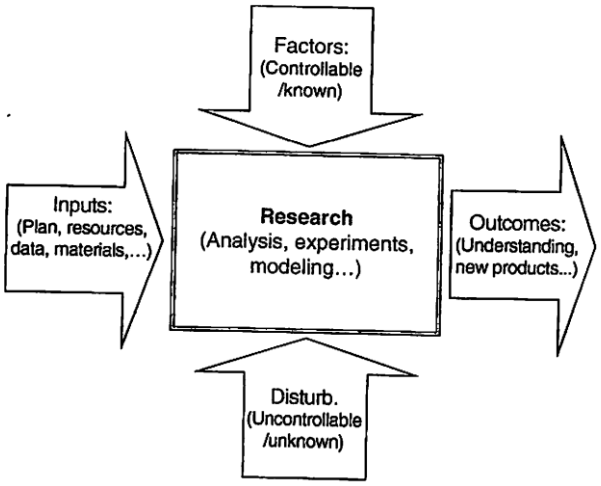


What is NOT research?

- Simply gathering information
- Merely rummaging around for hard-to-locate information
- Transfer of facts from on location to another

For example, the term "research" is often used for describing the act of information discovery in our daily life. For example, if one is looking for a new car, he/she may do "research" on various features, models, safety records, price, etc. When looking for a job, one would "research" the websites of companies with openings. These types of everyday exploratory activities are good for an individual's purposes, but no contribution to the general knowledge of a professional community.

We can view research as a system…..

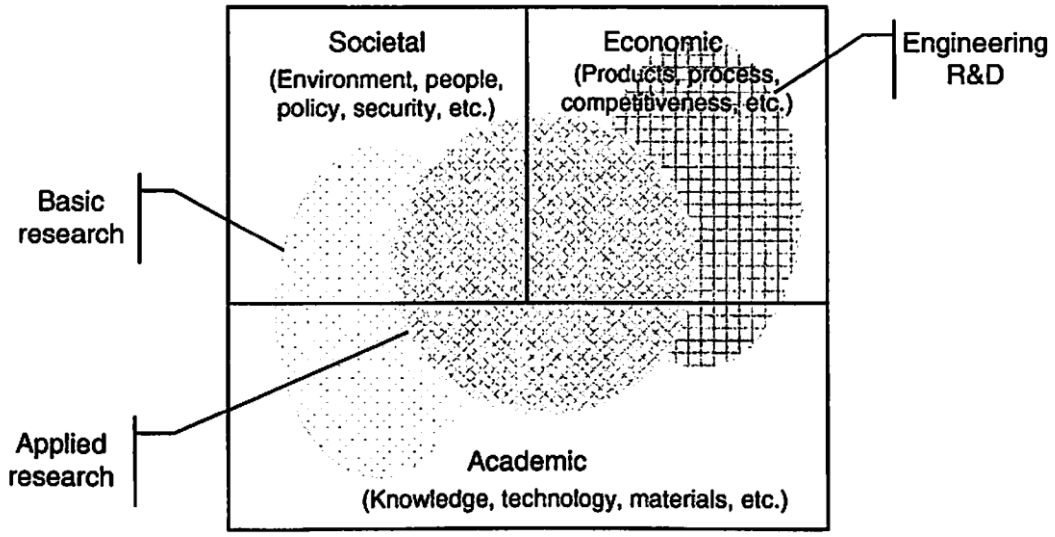


General characteristics of research:

- **Scientific research is a structured study with a plan to execute and document the process and results.**
- **Research work always has various assumptions.**
- **Much research, particularly basic research, is normally hypothesis guided.**
- **The entire research process, or methodology, is just as important as the specific methods used for research success.**
- **Research methods and outcome always have limitations.**
- **The outcomes from research should be independently verified or recognized by other professionals.**

Difference between Basic Research and Applied Research – see diagram in the next page.

Different Areas of Research



Engineering R&D is not research, as it is directed to a specific product or outcome.

- **Basic research to explore knowledge**
- **Applied research to solve problems**
- **R&D to generate new artifacts**

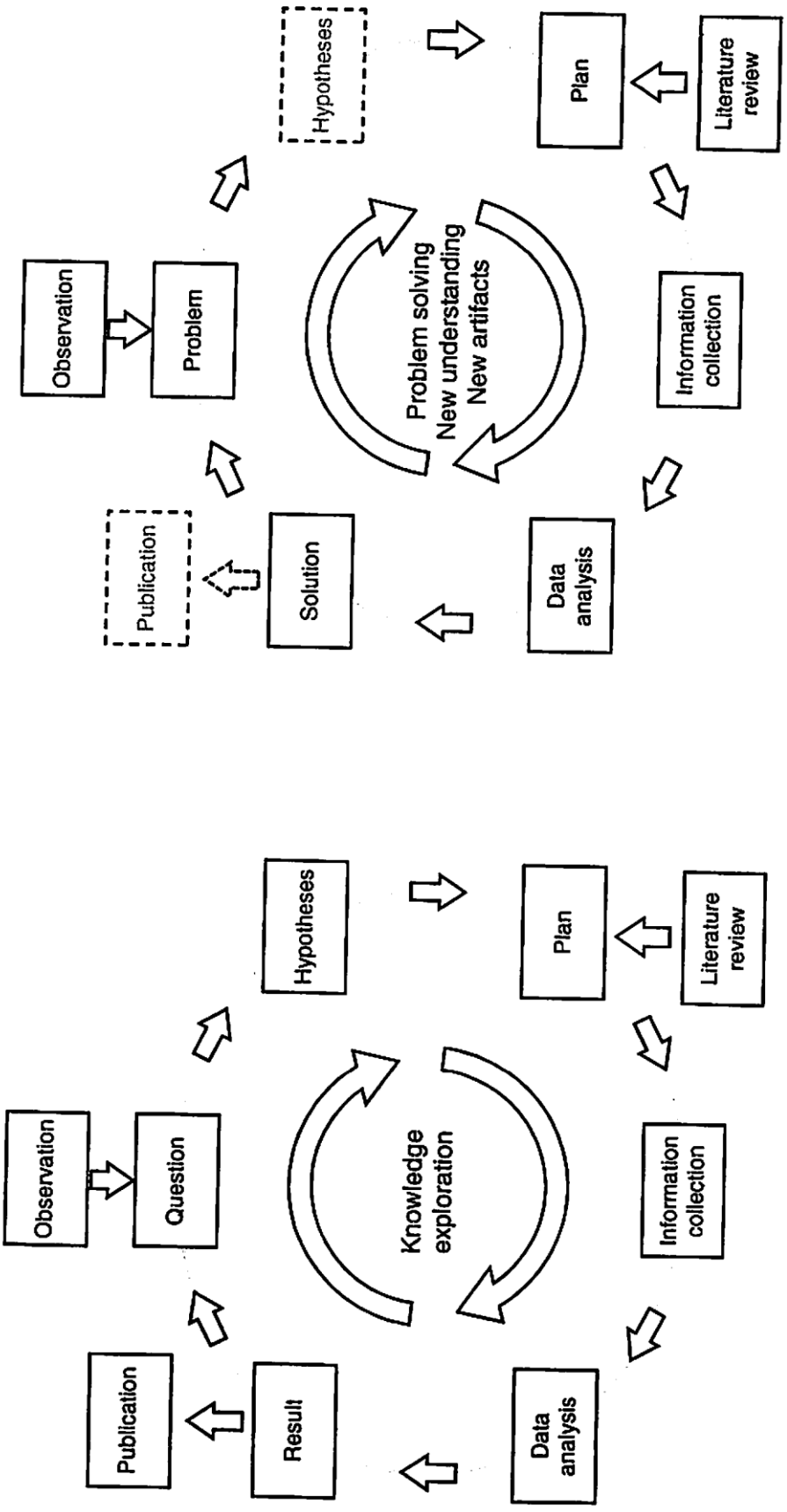


Figure 1.2 Overall processes of basic and applied research. (a) Basic research, (b) applied research and R&D.

Research is a part of higher and graduate educations. Figure 1.4 shows the significant increase of doctorate degree recipients in engineering and science fields from US universities in recent 20 years (NSF 2018).

Research training and projects can start at an undergraduate or master's graduate level. Many universities offer a dedicated course on research methods for master's graduate students and some universities offer introductory courses and programs of research for undergraduate seniors (Depaola et al. 2015). A research course opens students a new opportunity to engage in creative and critical thinking that leads to hands-on engineering applications.

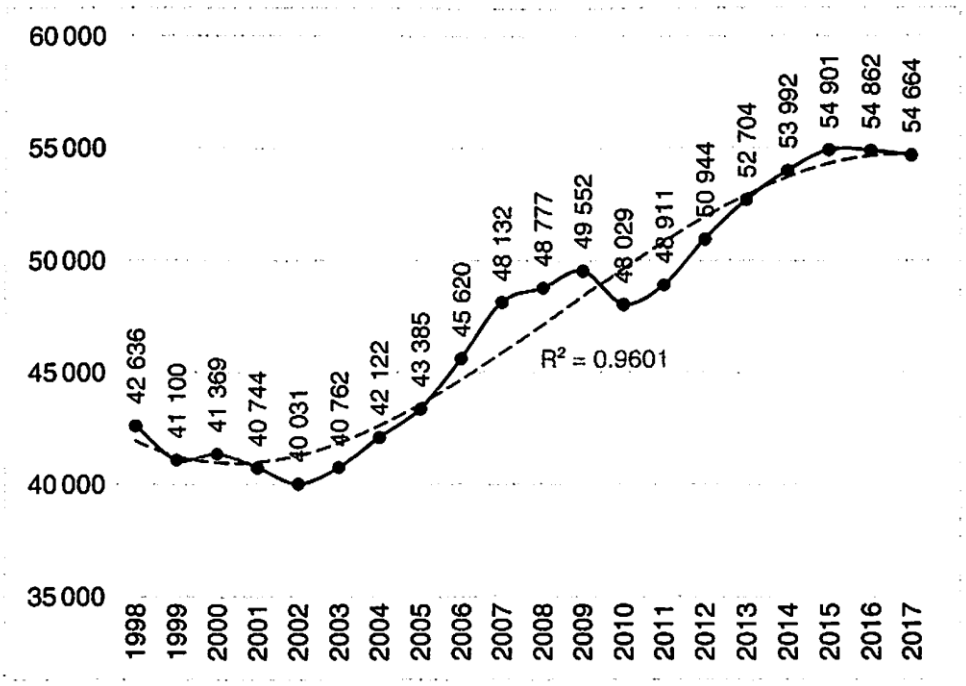


Figure 1.4 Doctorate recipients in engineering and science from US universities. Source: Data from NSF (2018).

Benefit to university students undertaking research:

Through completing a research thesis or capstone project, students can also deeply explore something they have a passion for and enrich their understanding of the topics. They can apply their learned skills do better future research and conduct industry projects they work on. In addition, research can help students in the following ways:

- Improve critical thinking and intellectual independence
- Develop creativity and problem-solving skills
- Have opportunities to communicate special ideas
- Enhance your determination and perseverance

2. Building Blocks of Research

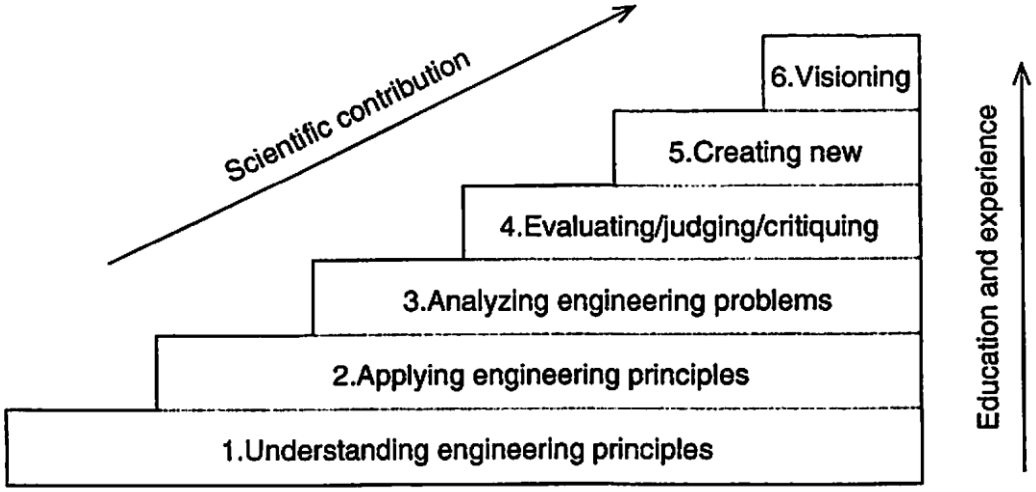
The essential elements of doing research

#1 - Innovative Mind

Motivations to research

Intrinsic motivating factors include curiosity, determination, and/or enjoyment of solving a challenging problem. For example, researchers may have strong personal preferences for a particular subject or direction of research.

Levels of thinking



Critical Thinking

Critical thinking is a skill and process, which includes analyzing, assessing, and challenging an observation on a subject. Some authors defined critical thinking as "self-guided, self-disciplined thinking which attempts to reason at the highest level of quality in a fair-minded way" (Elder 2007). Critical thinking plays a more important role than that of observation, which does not necessarily generate a research question. Critical thinking questions may include

- Questions beyond norms or traditions
- Logical evaluation of evidence, process, and conclusions
- Connections between similar or different ideas
- Systematical review and consideration of all aspects and elements
- Open minded to be challenged and to different perspectives

Assumptions

Assumptions are the foundation and conditions that affect the outcome of research. Assumptions help narrow the scope of research work, effectively drive the execution process, and guide the focus of research work. In addition, any research task, such as data collection and analysis, is under certain assumptions based on physical constraints and situations. Assumptions affect the ways the data is gathered, analyzed, and concluded. Assumptions also indicate how far we have gone to prove findings.

Hypothesis

Before doing a research task, we often have a specific aim or expectation of the outcomes. Such an expectation may be formulated as a hypothesis, which is a predictive statement based on our knowledge, experience, and research targets. Therefore, most research, particularly basic research, is hypothesis-driven. The corresponding tasks are to test the hypotheses and draw conclusions, refer to Figure 1.6.

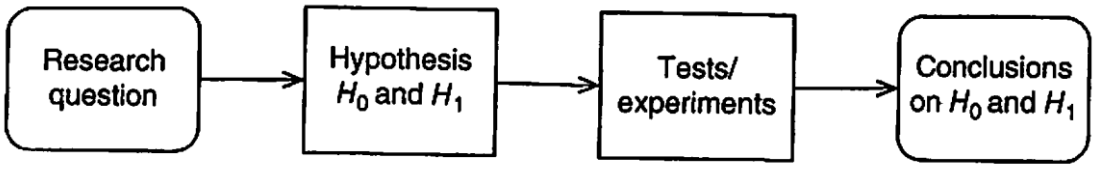


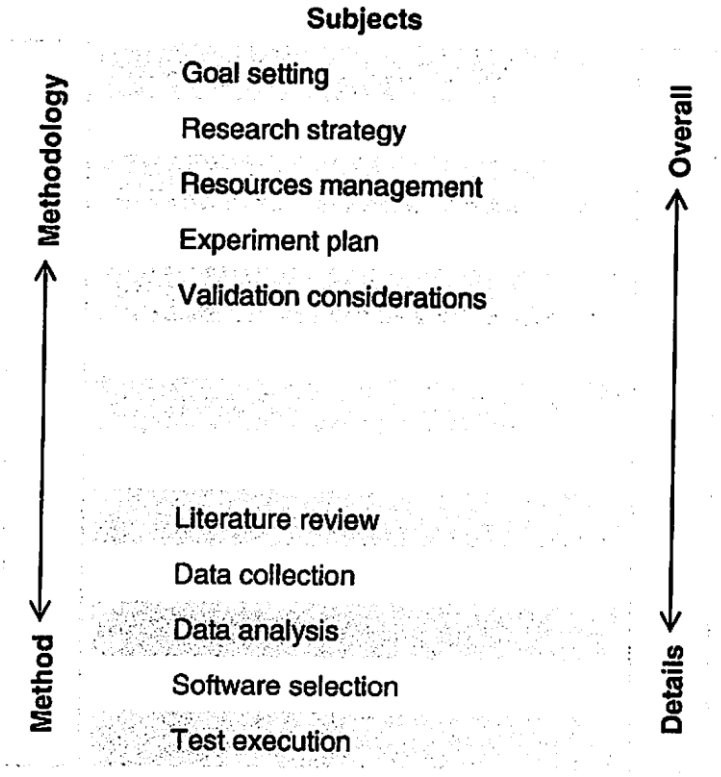
Figure 1.6 A process flow of hypothesis-driven research.

Methodology

Methodology is a general research strategy and procedure. It refers to all methods used to meet research objectives and all perspectives of a research process as a whole. Research methodology may include data collection, analysis approaches, equipment and facilities, process, validation, and so on.

Methods

A method is a specific approach or tool used to do a research task. For example, we may use probability theory as a tool for data analysis. In most cases, researchers in the same field prefer the similar methods.



Research Community

(i) Environment

Most of research is teamwork-based. Teamwork-oriented spirit and environment is fundamental for a research project initiation and execution. For example, observe the teamwork at a college, where many graduate students have advisors and work in well-established laboratories supported by technical personnel.

(ii) Ethics

Ethics in research, including honesty, objectivity, respect for intellectual property, confidentiality, and so on, plays an integral part in research. Many professional associations and sponsors have developed codes and policies that outline ethical behaviors of researchers.

(iii) Resources

The more resource the better

3. Types of Research

Basic Research, Applied Research and R & D

Basic Research

"Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view."

Some examples:

- High-power alternative energy conversion
- Computational thinking in biological engineering
- Modeling for cardiac tissue manufacturing
- Theoretical framework in systems engineering
- Engineering artificial cells

Applied Research

"Applied research is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective."

Therefore, the main difference between basic research and applied research is whether a research effort has a practical objective to real-world situations and applications. Much engineering research, such as running experiments, advancing new technology, and conducting case studies, is applied research.

Engineering R & D

Engineering R&D is a technical invention, focusing on the form, function, and capabilities of implementation into products to the marketplace. Engineering R&D may be defined as (Moris 2018):

> *"Experimental development is systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes."*
> *"Development: systematic use of the knowledge and understanding gained from research for the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes."*

Comparison

Characteristics	Basic research	Applied research	Engineering R&D
Overall goal	Exploration to new knowledge or theories	Expand or create technology/knowledge	Develop or improve products and processes
Focus	Fundamental and new understanding	New process, materials, parameters, etc. (in lab)	Specific realization (in production)
Applicability	General/universal principles	Predictable, general scope	Specific situations or problems
Contribution	Theory (maybe revolutionary)	Technology and inventions	New products, technological reference
Typical funding	Government and foundations	Government, foundations, industry	Industry internal, sometimes joint ventures
Timeframe	Long term	Midterm, fixed with certain flexibility	Short term, fixed
Practitioners	Scientists in academia and institutes	In variety of settings and combinations	Industry engineering professionals
Selection	By researchers, guided by sponsors	Selected by researchers based on necessity	Based on demand and directives
Commercial value	No or unclear	Good for a long term, influential	Short term, expected, and direct
Success rate	Low risk, high uncertainty	Medium risk and uncertainty	Low risk, high certainty
Outcome	Publication	Publication, internal reports, and/or patents	Mostly internal reports and/or patents

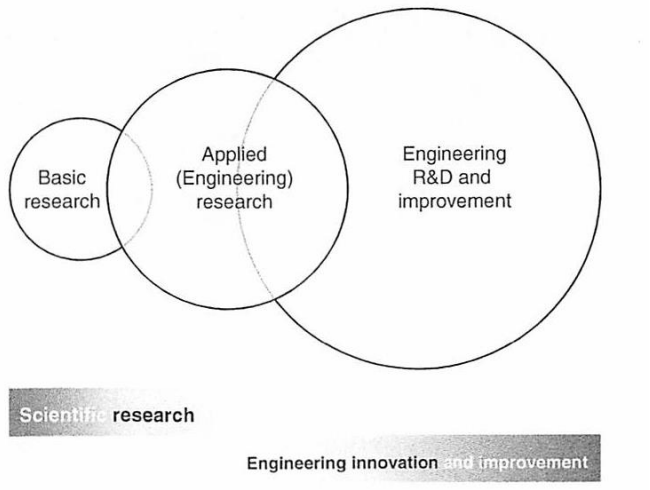


Figure 1.9 Types of research and development.

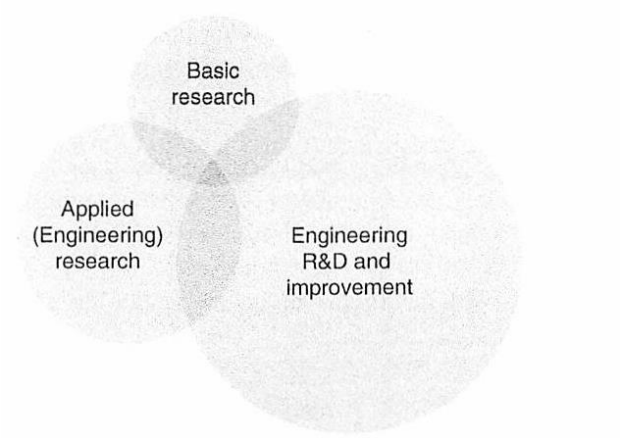


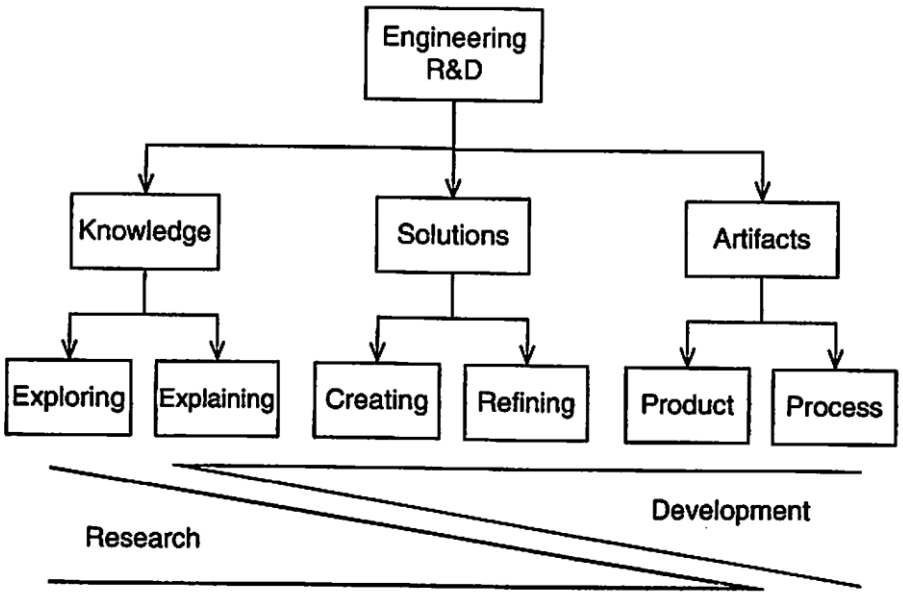
Figure 1.10 Relationship among three types of research.

Figure 1.10 shows an interesting relationship among the three types of research activities. Each of the three types of supports, promotes, and drives the other two.

The general goal of engineering R&D is to improve the condition or functionality of particular goods. For instance, a research project may aim to increase the calculation speed of a new computer system, create a new algorithm for autonomous vehicles, or design a new software language.

A R&D objective can come in various formats and often is one of the three interconnected types or a combination of the three (Figure 1.11).

1. To explore, explain, or verify new *knowledge* or phenomenon; or synthesize existing knowledge,
2. To investigate and find *solutions* on a major problem by understanding causational relationship, or
3. To develop (conceptualization, create, and evaluate) a new *artifact* or technology, such as a tool, product, and process.



4. Validity of Research Results

Research Validity

In general, research and its results should be based on objective facts rather than an opinion. Rigorous, precise, thorough methods and processes should be used to keep the results and conclusions objective and correct. Logical arguments and meaningful conclusions must be supported with the evidence.

Table 1.3 A comparative view between internal and external validity.

Aspect	Internal validity	External validity
Definition	Soundness of work and outcomes	Generality to other situations and real world
Meaning	True and accurate for the study	True and accurate for similar other studies
Relationship	Essential, itself	Additional, on top of internal validity
Significance	Important to applied research and R&D	Important to basic research

Internal Validity

Table 1.4 A checklist for internal validity.

Question	Yes	Maybe	No
1. Is problem statement/hypothesis established correctly?			
2. Are methods used appropriate?			
3. Have measurement instruments been calibrated?			
4. Are the samples selected randomly?			
5. Are the findings aligned with the problem statement?			
6. Can the logic be explained?			
7. Is any interpretation lack of data support?			

External Validity

Table 1.5 A checklist for external validity.

Question	Yes	Maybe	No
1. Are the assumptions acceptable to other setting?			
2. Will the same results can be obtained from another lab?			
3. Do the conclusions apply in the real-world situations outside the lab?			
4. Can this plan carry over to other place or site and get the same results?			

Assessment

A validation process may include four steps:

1. Set up an environment and design realistic scenarios
2. Build a prototype with the new artifact
3. Simulate the prototype against in the scenarios in the environment
4. Assess the results

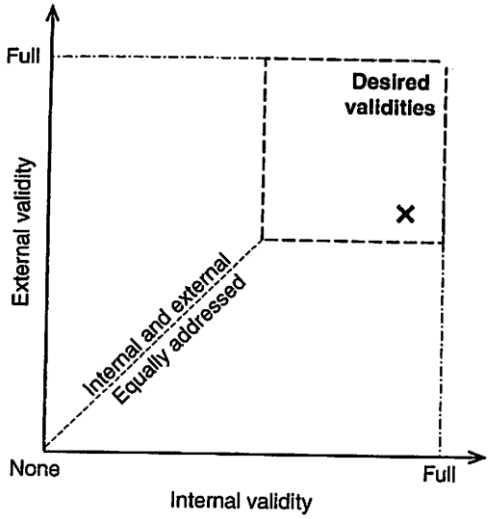


Figure 1.14 Overall validity target of research results.

Publication

One of the requirements for research is the professional communication and dissemination of new knowledge. Publication is an important way to advance knowledge and get validation. In general, all basic research and most of the applied research results are published via peer review academic journals and professional conferences. The peer review process is a good validation process.

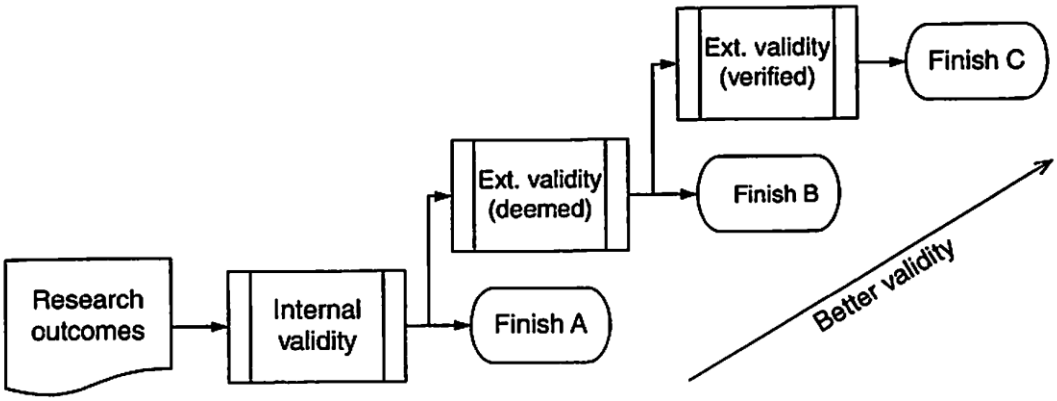


Figure 1.15 Validity levels of research results.

Further Developments

After successful validation, a next step for applied research is to scale up from specific laboratory conditions to practical, real-world conditions. The scaling-up tests may be adding realistic conditions of practice, extending to larger sets of subjects, or a combination of both, refer to Figure 1.16.

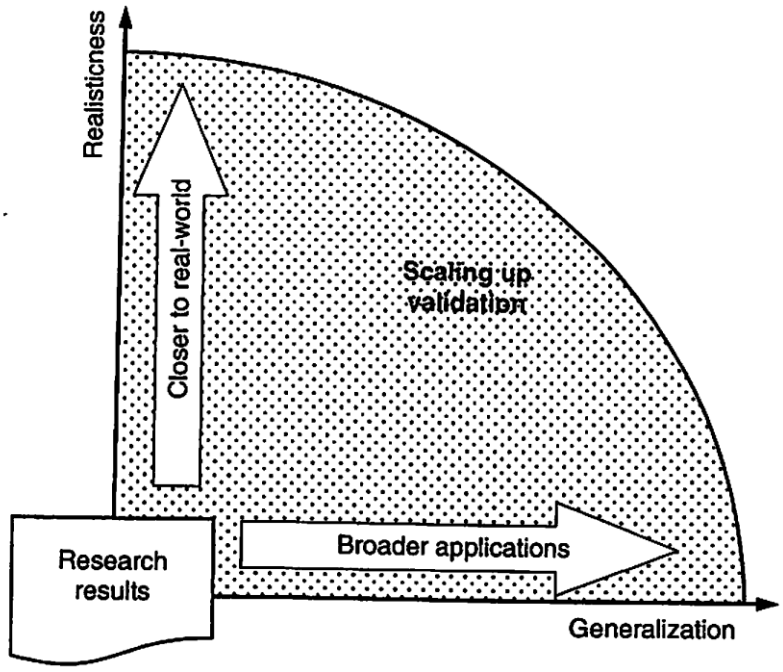


Figure 1.16 Further development of research.

5. Summary

Introduction to Research

1. Research is about innovation and seeking new knowledge in a systematic way.
2. Research normally follows a certain process of planning, literature review, information collection, data analysis, and results discussion, etc.
3. Research is objective driven; the outcomes of research should be conducive to its predefined objectives.
4. Research should have various types of impacts on academic, economic, and/or societal aspects.
5. Research is an integral part of higher and graduate education.

Building Blocks of Research

6. Motivation is a foundation of research success. While the motivations may include curiosity, career, and education needs.
7. Analytical, critical, and creative thinking plays an integral role in research.
8. Assumptions are the foundation and conditions for research work. Assumptions may or may not be completely and explicitly stated.
9. Research is often for hypothesis proving or problem-solving. Hypothesis, normally in format of H_0/H_1, may be predictive statements based on research aims.
10. Methodology is a general research strategy and procedure, while a method is a specific approach or tool used in research. Both terminologies sometimes are interchangeable.
11. Research is teamwork in an environment, meeting ethics requirements, and with funding sources.

Types of Research

12. There are three types of research: basic research, applied research, and R&D. They closely connect each other.
13. Basic research is fundamental or theoretical work for new knowledge. Applied research is for both new knowledge and practical aims or problems. R&D is a technical invention, focusing on new products and technologies.
14. The outcomes of engineering R&D can be new knowledge, solutions, and/or artifacts.
15. The knowledge exploration in research can be descriptive, exploratory, analytical, and predictive. Engineering research is more in the latter two types.

Validity of Research Results

17. The validity is the base of research work and its results. Sometimes, validity is called in different terms, such as "reliability," "accuracy," "objectivity," "generalizability," and "credibility."
18. Internal validity is about the soundness of work and outcomes, referring to the study itself.
19. External validity is about the generality of work and outcomes to other situations and real world, or how well the work and outcomes from one setting applicable to another.
20. Internal validity is a foundation of external validity.
21. Sampling methods used and sample sizes are the two important factors to internal validity.
22. The specific assumptions largely affect the external validity of research and its outcomes.

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