1

Research Overview

1.1 Introduction to Research

1.1.1 What Is Research?

Research is a universal word. Professionals in almost all disciplines are prosecuting doing research, such as in science, engineering, medicine, languages, literature, history, and business. There are various definitions of research. However, the process and requirements of research in some areas, such as medical science, might be better defined than that of other fields. While difficult to define research comprehensively and precisely in one sentence, we can understand research from its various aspects.

1.1.1.1 Seeking New Knowledge

According to Merriam-Webster Dictionary, the word research is derived from the French "recherché," which means "to go about seeking." Research concerns the seeking and creation of new knowledge and understanding the principles and characteristics of a phenomenon. For example, another definition of research is "the process of finding out something that we don't already know" (Hazelrigg n.d.). The new thing should be interesting or of concern to a profession or humanity. Research can be any kind of investigation that intends to uncover new facts.

The words "what" and "why" may be used to show what research is about. Knowledge takes two forms: "know that" and "know why." The "know that" may be called declarative knowledge, which represents ideas and understanding. As such, declarative knowledge is relatively easy to teach and learn. The "know why" is about a type of functional knowledge, which varies with individual capability.

In many cases, scientific work includes applied research (R) and engineering development (D) called research and development (R&D) in short. Such R&D efforts can be either applied research, development, or a combination of both and in context of "know how." The yields of most engineering and technical R&D

Engineering Research: Design, Methods, and Publication, First Edition. Herman Tang.

are new or improved physical artifacts, such as software, products, and processes. Sometimes, the research characteristics of R&D may be debatable as far as its contributions to new knowledge.

A key to research is an innovation to professional community at large. Think about some efforts that may look like but are not research. Here are a few common types (Leedy and Ormrod 2016):

- 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. Therefore, such acts and efforts of information search are not scientific research because the information is not new to professional community.

1.1.1.2 A Systems Viewpoint

We may view a research project as a system (Figure 1.1), which can have different objectives and tasks, such as analysis, experiment, and computer simulation. From a system viewpoint, doing research is to invest inputs, consider influencing

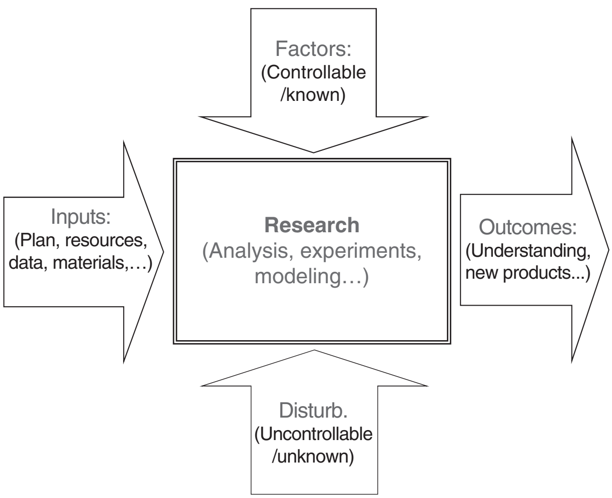

Figure 1.1 A system view of research project.

factors and distributions, and do original and diligent work for the expected outcomes. Accordingly, one of the important characteristics of research from a systems viewpoint is to deal with the complex relationship among inputs and controllable factors.

For a defined purpose or curiosity, knowledge exploration starts from observations. Figure 1.2 shows the overall process flow of systematic knowledge exploration: (i) basic research and (ii) applied research and R&D (problem-solving).

After identifying a research question or problem, we need to establish our guess, or hypotheses, for basic research. Based on the question and hypotheses defined, we then develop a detailed study plan. For a relatively simple problem, we may directly address it.

Following the plan, we conduct the study, which includes data collection, analysis, and interpretation. In most cases, we submit our findings for publications to share with others. It is often the case that research results promote new questions. Following this circular process, the understanding and knowledge on a particular subject can continuously deepen and widen.

Exploring new knowledge never ends. "Research is iterative and depends upon asking increasingly complex or new questions whose answers in turn develop additional questions or lines of inquiry in any field" (ACRL, Association of College and Research Libraries 2016). Research continuously advances to new levels of knowledge and innovation.

1.1.1.3 General Characteristics

Research in all disciplines shares common characteristics in addition to the systematic exploration:

- 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.

It may be a good exercise for reader to think about known research for these general characteristics. For example, what are the assumptions for a completed research project? Are they explicitly stated? Other questions may include the nature, method, and procedure used in the research.

Engineering R&D share common principles and methods from the research in other scientific fields, such as medical and social sciences, but may have some

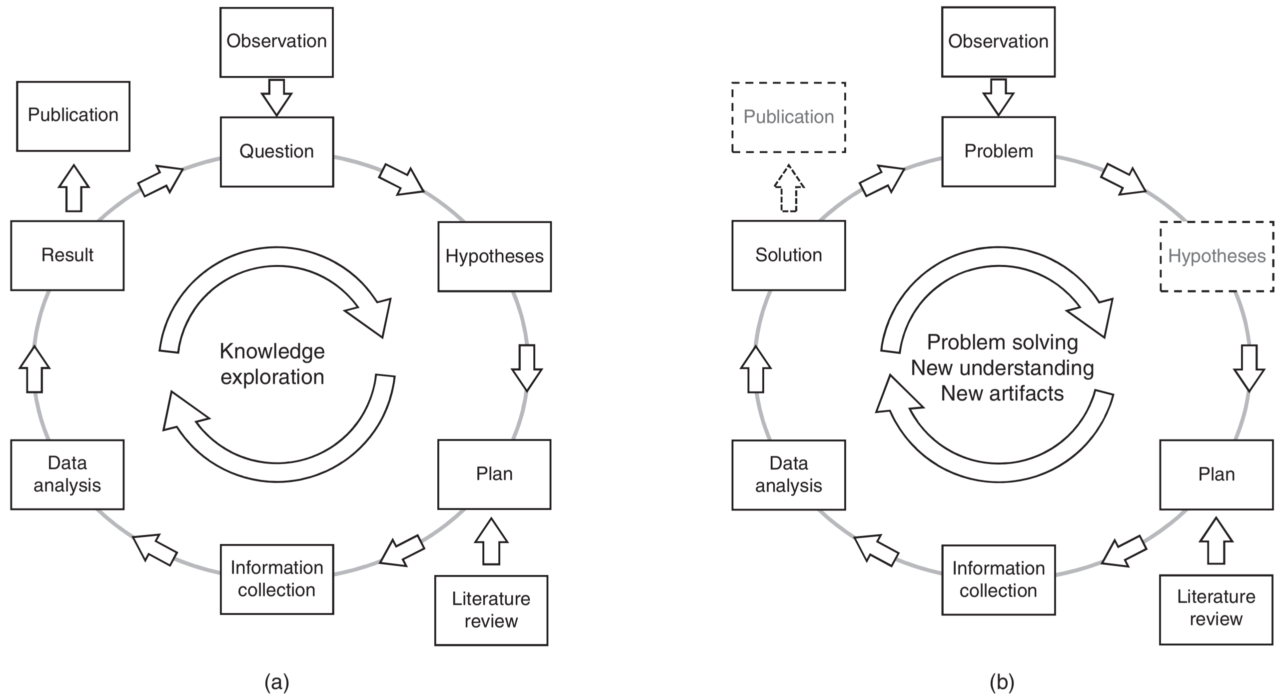

Figure 1.2 Overall processes of basic and applied research. (a) Basic research, (b) applied research and R&D.

different emphases, characteristics, and practices. Engineering researchers can and should learn from the professionals in other disciplines to improve their research methodology. More discussion on engineering R&D is in a later section of this chapter.

1.1.2 Impacts of Research

1.1.2.1 Impacts on Societies

Research work needs resources, including funding, personnel, and facilities. A question often asked is “what is the return on that investment?” Therefore, researchers must provide the justification of a research project with positive impacts and effects.

The impacts of research can be the overarching benefits for human society. Research can contribute in many ways and areas, such as technological developments, environmental impact, economic benefits, health and wellbeing, national interests, and policy change.

The impact of research also depends on the type of research. Figure 1.3 illustrates how the three main areas of research (i.e. academic, economic, and societal) can have significant impacts. Situations are also various in terms of the designed impacts of research. For example, a research project may be purely scientific without an immediate impact on society. If a R&D project is for commercialization, the product may make a significant technological advance.

The impacts from a research project depend on various factors, such as the type, objective, and size of a research project. For example, basic research, to be discussed in Section 1.3.1, is to expand humanity’s knowledge. Two criteria related

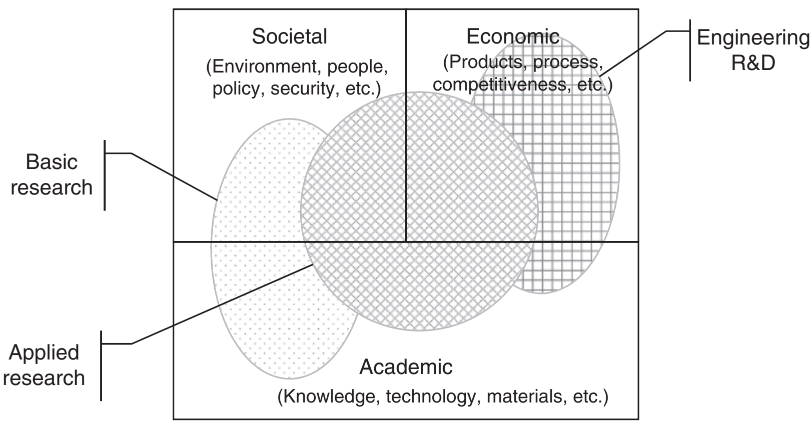

Figure 1.3 Main areas of research impacts.

to the overall evaluation of basic research are intellectual merit of a new discovery and the broader impact on society.

While applied research and R&D have different applications, the impacts of such application-oriented research may be different from those of basic research. Industrial corporations often consider commercial advantages to fund R&D projects. In addition, corporations may support research institutes for basic and applied research as well.

1.1.2.2 For Specific Objectives

As discussed previously, the general objectives and benefits of different types of research are different and with substantial overlap:

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

In most cases, they may build on each other in succession through their similar goals. For example, new knowledge derived from basic research inspires theories leading to applied research and R&D. R&D in turn can raise demands to conducting basic and applied research.

Some funding sponsors focus on the solutions of particular problems or a specific area. The research projects funded by the sponsors may have very specific objectives and criteria. A granted research project should meet the sponsor's requirements, such as a better understanding of the phenomenon in question, more accurate predictions about future events, additional interventions for a better quality of environment or life. It is important to note that you as a researcher can have your idea first and then try to find and matching, funded opportunities.

The outcomes of a research project should be conducive to its predefined objectives. Here are a few examples of basic and applied research supported by the US government agencies:

- The Basic Energy Sciences program of the US Department of Energy is to "discover new materials and design new chemical processes" (DOE n.d.-a).
- The Advanced Scientific Computing Research program is to "discover, develop, and deploy computational and networking capability to analyze, model, simulate and predict complex phenomena important to the Department of Energy and the advancement of science" (DOE n.d.-b).
- The Secure and Trustworthy Cyberspace (SaTC) program of US NSF states, "The goals of the SaTC program are aligned with the Federal Cybersecurity Research and Development Strategic Plan (RDSP) and the National Privacy Research Strategy (NPRS) to protect and preserve the growing social and economic benefits of cyber systems while ensuring security and privacy" (SaTC n.d.).

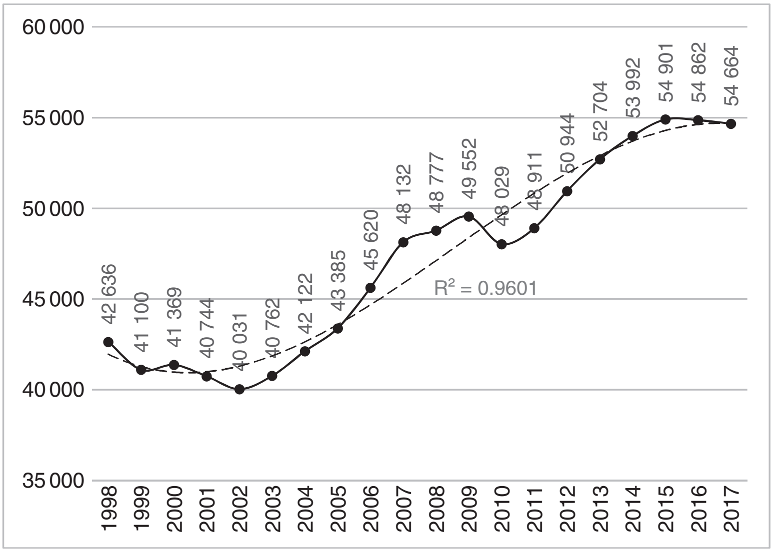

Figure 1.4 Doctorate recipients in engineering and science from US universities. Source: Data from NSF (2018).

- The Science Mission Directorate of NASA "targeted technology investments fill technology gaps, enabling NASA to build the challenging and complex missions that accomplish groundbreaking science" (NASA n.d.).

1.1.2.3 Benefits to Student Researchers

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.

Some students consider doing research simply out of interest without any in-depth concern for anything else. Without much experience, they may be hesitant to choose research opportunities in curriculum. Before doing research, students should discuss with professors and experienced researchers and ask what prerequisites are needed. With the guidance and encouragement by experienced researchers and professors, students can quickly grow in motivation and understanding, start to develop their research skills, prepare to pursue a higher degree, and to become good researchers. A study showed that many undergraduate students discover their passion for research through exposure to simple research projects (Madan and Teitge 2013). A large survey with 15 000 respondents indicated that undergraduate research significantly increases understanding of how to conduct research and confidence in research skills (Russell et al. 2007).

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

Research work provides examples and accomplishments of students to their peers and employers, which offers insights to a person's credentials and background as well. In today's technical professions, if someone has a well-rounded mix of skills, he/she may stay relevant in a competitive position.

1.2 Building Blocks of Research

We refer to building blocks here as the essential elements of doing research. They include several key factors, including knowledge, competence, information, teamwork, resources, etc. These building blocks are essential to, as Dr. Richard Miller, President of Olin College of Engineering, said: "Learning things that matter; learning in context; learning in teams. Envisioning what has never been and doing whatever it takes to make it happen" (Ark 2019). In addition to proper knowledge, motivation and critical mindset play critical roles to research work and success. We address these building blocks in this section and will have more in-depth discussions in the following chapters.

1.2.1 Innovative Mind

1.2.1.1 Motivations to Research

In most cases, researchers are generally enthusiastic about what they do. For example, a researcher stated, "my research is motivated by interesting challenges arising from the growing size and complexity of modern pattern recognition problems in the sciences, engineering and social media" (Kpotufe 2014). In contrast, if burdened with a “have to do” mindset, one will not be very successful in their 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.

While some motivation sounds extrinsic (such as educational requirements, studying for a master’s or doctoral degree and professional career requirements, such as for employment, promotion, and recognition), these are all actually intrinsic motivation because researchers determine to pursue their career interests or educational paths. It still comes down to someone being personally motivated.

As general interests change and advance along with new technologies and community demands, it is important that an individual researcher’s interests be in line with overall trends. For instance, in Computer Science and Engineering fields, students would most likely to do research in one of the significant advancing subjects: networking technologies and distributed systems, embedded systems, ubiquitous computing, interoperability and data integration, object-oriented programming, human–computer interaction, software safety, security and cryptography, and so on. In other words, successful researchers focus on the future and stay in the present.

1.2.1.2 Thinking and Research

As with any learning knowledge or skill, human cognition has several levels. Refer to Figure 1.5 for the general growth of capability and contribution of professionals.

In colleges, undergraduate education focuses on the comprehension of knowledge and it is application on Levels 1 and 2. Once proficient at the first two levels, students can analyze real and complex problems with their knowledge (Level 3), which is a starting point of a professional career, research, and creativity. With

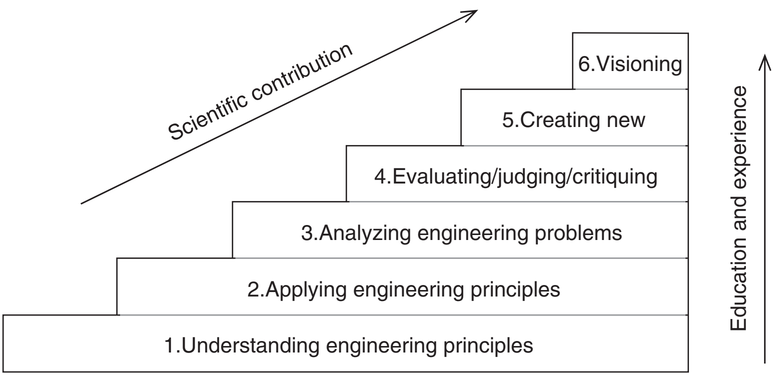

Figure 1.5 Thinking levels and research capability.

analysis and problem-solving, they become more capable to check, assess, and critique the work and achievements of themselves and others. Such capability of evaluation (Level 4) includes critical thinking and analysis, which is a foundation for creating and producing new understanding and/or artifact (Level 5). At the top level (Level 6), researchers are grown: becoming visionary leaders to predict and guide research directions. The higher level of knowledge and thinking, the more contributions we may have on the scientific and professional community.

Appropriate knowledge is often a prerequisite for critical thinking, creating, or improving solutions. Technical knowledge, along with other factors, influences cognitive capability, which plays an essential role in the success of research. We can learn particular thinking skills, such as deductive logic and inductive reasoning, from training and practice.

1.2.1.3 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

It is true that "many ideas that were previously thought of as 'facts' or 'theories' were debunked by others who did not give up in their quest to prove that inaccuracy of those ideas. Those who continued researching against what was 'known' were thought of as crazy" (Laird 2018). Thus, critical thinking is a key for us to challenge the existing understanding and generate new ideas and/or new methodology. We can find new opportunities and initiate new studies from thinking critically and challenging the existing status or conclusions.

Practicing critical thinking in a literature review often generates new ideas and questions, which is also an effective way to initiate a new research proposal. In the literature review section of published papers, the words like "however" and "although" are often used to challenge the existing status or scenarios. For example, the authors stated, "Although there have been considerable developments in manufacturing technologies and processes, the actual scope and elements of manufacturing systems are complex and not adequately defined" (Esmaeilian et al. 2016). In critical thinking mode, we may also question ourselves on different aspects of research, such as on its assumptions, data reliability, method adopted, interpretation, conclusions, and potential applications.

In workplace, there is an accountability vs. responsibility relationship, as with superiors and subordinates. In a university, there are student researchers and faculty advisors. For research, we should try to think outside the box on research as much as we can but not constrain our critical thinking based on work relationship. In conducting research, our technical discussion should be based on the convincible ideas and facts, rather than authority. Senior researchers must encourage and guide novice and young researchers on critical thinking and innovative initiatives to challenge the existing principles and status.

1.2.2 Assumptions and Hypotheses

1.2.2.1 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.

Assumptions may or may not precisely reflect the real world. We should avoid assumptions that are extremely restrictive. Similarly, too many assumptions may result in the research becoming over simplified. If it turns out that the assumption is not reasonably accurate, then the findings and results may not be meaningful or externally valid. In other words, successful research outcomes are conditional to appropriate assumptions.

Assumptions may be broken down into three types: epistemological, ontological, and methodological. They are about the ways to acquire the knowledge, the nature of the world and human being in social contexts, and analysis of the methods used, respectively. Most assumptions in engineering applied research and R&D are methodological, related to the methods, data, and process.

Assumptions should be an integral part of research publication to make sure that the audience is aware of them. The assumptions, in either quantitative or qualitative form, should be stated in a proposal and in a result report later on and sometimes even in the title of a proposal and paper. For instance, this study clearly stated assumption in its title: "New two-phase and three-phase Rachford-Rice algorithms based on free-water assumption" (Li and Li 2018).

The abstract of a paper may include the assumptions as well. For example, a paper stated its assumptions thus: "This paper shows the usual inconsistency made in the linear elastic fracture mechanic, which is to estimate plastic zones

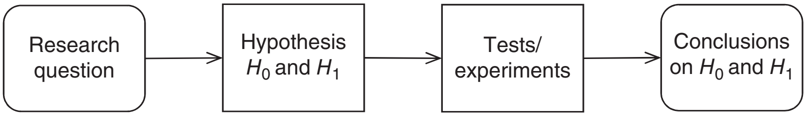

Figure 1.6 A process flow of hypothesis-driven research.

(PZ) from a linear elastic (LE) analysis with correction of the PZ size based on assumptions of equilibrium" (Sousa and Figueiredo 2017). Another paper indicated, "… satisfies certain mild assumptions which we outline below" (Razaviyayn et al. 2013).

Sometimes, researchers consider some assumptions so obvious not to even mention them in a proposal or paper. However, even though they are not explicitly stated, the assumptions do exist.

1.2.2.2 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.

For example, a paper had its hypothesis statement (Davoodi-Nasab et al. 2018):

$$H_0 : \beta_1 = \beta_2 = \beta_3 = \cdots = \beta_k = 0$$
$$H_1 : \beta_j \neq 0, \text{ for at least one } j$$

Where, the null hypothesis (H_0), as a starting point or a default position: all β_j are zero. The alternative hypothesis (H_1) is stated that at least one β is not zero.

Although stating a hypothesis mathematically is typical, not all researchers do so explicitly, particularly for applied research and R&D projects. There are various ways to state the hypothesis. For example, a paper stated, "The hypothesis of rigid adherents is here assumed" (Santarsiero et al. 2017). Another example expressed, "To evaluate the hypothesis that a reduction in tensile strength could be associated with some sort of reaction and/or interaction between HALS" (Staffa et al. 2017).

For the research using statistical analysis, we should explicitly state the hypotheses in format of H_0/H_1. We should also discuss the corresponding research tasks and results based on the stated hypotheses, which will be discussed more in Chapter 2.

1.2.3 Methodology and Methods

Both methodology and methods are the keys in research and play combined roles in research success. We often use the two terms of methodology and methods interchangeably in our professional communication. However, when we prepare and conduct research, it would be better to understand their differences and relationship. In a general sense, methodology is a broad scope and overall view of research, while methods are the specific approaches to conduct the research.

1.2.3.1 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.

Overall, research methodology addresses the objectives and procedure to a research project: what, why, and how to collect and analyze data. We develop a methodology by selecting and justifying a particular method to be used. For instance, one paper summarized the methodology for systems engineering research (Caillaud et al. 2016) while another is on ergonomic product design (Dianat et al. 2018).

1.2.3.2 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.

As a tool, research methods may themselves be research topics as well. For example,

> *"A new method for the automatic sketching of planar kinematic chains"* (Yang et al. 2018).
> *"A new approach to compute temperature in a liquid-gas mixture. Application to study the effect of wall nozzle temperature on a Diesel injector"* (Payri et al. 2017).
> *"The New EDrives Library: A Modular Tool for Engineering of Electric Drives"* (Haumer and Kral 2014).

Interestingly, there is no clear cut difference between the methodology and methods, refer to Figure 1.7.

1.2.3.3 Process

Conducting research consists of multiple tasks, such as problem identification, goal setting, hypothesis establishment, data collection and analysis, interpretation of the results, and so on. Researchers organize and execute the tasks in a systematic, scientific process. Some researchers consider research process is a main part of methodology. However, we may view a research process as a collection of main efforts or steps in a certain sequence.

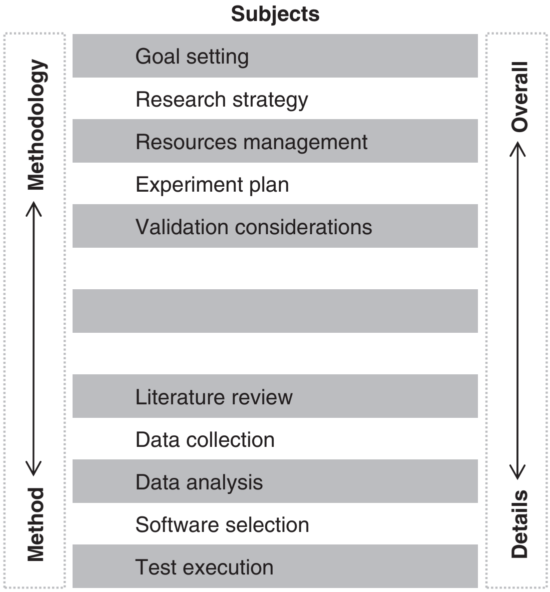

Figure 1.7 Research methods and methodology.

The process of a research project may be viewed as two segments: preparation and execution. An overall process flow is shown in Figure 1.8. We will discuss these items in depth in later chapters.

1.2.4 Research Community

1.2.4.1 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.

Experienced researchers normally have good connections with research organizations and in the professional community worldwide. The researchers may have better access to the latest research information, such as innovative methods, new progress, and development trends, from peers and facilities. Novice researchers should team up with and get help from experienced researchers.

1.2.4.2 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.

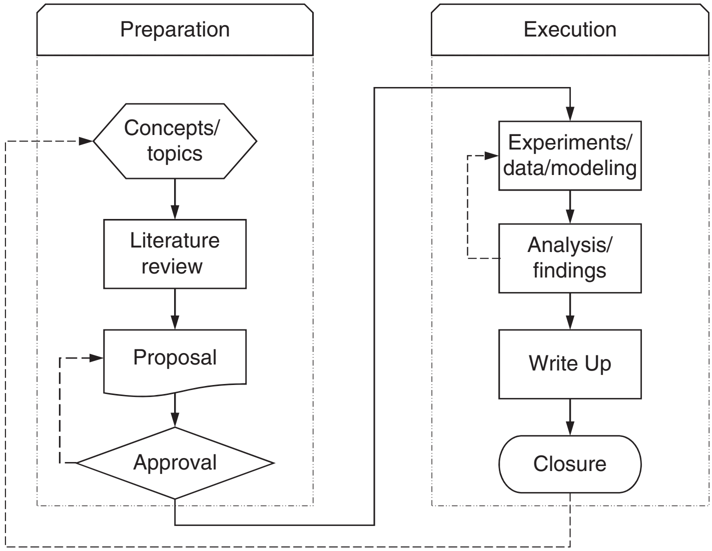

Figure 1.8 An overall process of research projects.

We must share and follow these ethical principles. For example, everyone should acknowledge the previous works of others in proposals and published papers. A common way to acknowledge others works is to have clear in-text citations and references. Inappropriate usages, purposely or unintentionally, of other's works can be grounds for accusations of plagiarism.

Another ethical consideration is related to human subjects, or obtaining data through the intervention or interaction with the individuals or from individually identifiable information. Work safety and ergonomics may be included as well. To consider human subjects, most institutions and organizations have an Institutional Review Board (IRB). An IRB is a panel of people to ensure the safety of human subjects in research and to assist in protecting human rights. A research project related to human subjects needs an IRB approval, which helps protect the institution and the researchers against potential legal implications from any behavior that may be deemed unethical. We will have more discussion on the ethical considerations in Chapters 2, 8, and 9.

1.2.4.3 Funding Sources

Research projects may be funded by various sources, including those internal to an organization, government agencies, philanthropy foundations, and industry partners. Surveys by the NSF showed that the US federal agencies provided about 44% of the $86 billion spent on basic research in 2015 (Mervis 2017). Private and philanthropy foundations also play an important role in basic research.

If a researcher is affiliated with a university, he/she should first contact the department or college research offices. Most research universities have internal funding and fellowship programs to support faculty and student research. In addition, most universities have an office for sponsored programs, which coordinates grant requests and helps researchers on external funding grant opportunities.

Depending on funding sources and sponsors, the nature and requirements of research projects vary significantly. For example, government-funded research is often on basic research. Quality publications are requested if funded by the US NSF. We will have more discussion on research funding in Chapter 2 for proposal development and on research administration in Chapter 7.

1.3 Types of Research

1.3.1 Basic Research, Applied Research, and R&D

1.3.1.1 Basic Research

Research is a creative and systematic work. We normally categorize it in three types: basic research, applied research, and R&D. A NSF document summarized the common definitions and understandings on the research categorization (Moris 2018):

> *"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."*

Another definition from the US Department of Defense for non-DOD respondents:

> *"Basic research: Basic research is defined as experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts."*

Therefore, basic research is to expand humanity's knowledge and investigate a natural event, process, or phenomenon. Such research helps build new frontiers of knowledge of how things work but no immediate commercial value or application are expected. Sometimes basic research is called pure or theoretical research.

For example, "While there has been significant progress in understanding how such decisions should ideally be made, there is a significant gap in knowledge about how humans actually make such decisions. This gap is a barrier to improving systems engineering and design practice. In this project, basic research towards addressing this gap will be carried out" (Panchal et al. 2017). Here are a few other examples:

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

Research institutions are a core team for basic research. For research universities and institutes, considerable amount of research is on basic research. The research divisions of large corporations also do basic research.

1.3.1.2 Applied Research

Applied research aims to explore new knowledge as well. A NSF document (Moris 2018) stated the definitions of 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."*

The definition from the US Department of Defense for non-DOD respondents is:

> *"Applied research: Applied research is defined as 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.

Here is an example of the research objective of a NASA research proposal: "the technical objective of this proposed project is to develop and experimentally validate key technologies needed for autonomous rover traversing on Mars-analog terrains. The goal is to reduce the number of sols needed to complete the MSR mission-required total traverse distance (i.e. 'fast traverse'). This will be achieved through increased rover operation 'duty cycle' and 'mean time between human interventions,' while utilizing limited onboard power and computational resources" (Gu 2017).

To address and resolve a real-world situation, applied research may be either technology-driven or problem-driven when seeking new understanding and knowledge. Researchers conducting technology-driven studies are primarily interested in a particular technique (e.g. neural networks) and looking for its development and new applications. The goal of such research is to advance techniques, create a new technology, and improve their capabilities. Most technology-driven research contributes incrementally to the technology advance. For example, a paper is titled "A facile ion imprinted synthesis of selective biosorbent for Cu^{2+} via microfluidic technology" (Zhu et al. 2017). To reach a problem's solution, we may use existing appropriate methods or construct new ones.

Some may challenge the idea that problem-solving is real research. We can determine this by examining whether the problem-solving research creates or extends our knowledge and benefits the professional community (in the form of publication), such as the paper addressed a practical problem as titled "An energy-efficient multi-objective optimization for flexible job-shop scheduling problem" (Mokhtari and Hasani 2017).

1.3.1.3 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."*

While it is true that many R&D projects are based on experimental investigations, it takes other forms, too, such as product development and manufacturing technology. The new findings and results of R&D can advance human understanding as well. However, due to commercial confidentiality, the achievements from engineering R&D are infrequently published and sometimes patented. The discussion of engineering R&D continues into the next section.

Applied research and R&D are often overlapped and used exchangeably. Apple and General Motors spent \$14.24B and \$7.8B on R&D in 2018, respectively (GM 2019; Apple 2019), which included basic research, applied research, and development – directly associated with their future products. Industry research is primarily to corner specific areas of a market, in order to be the first to market or protect intellectual property through patents and trade secrets.

The NSF document (Moris 2018) also lists some R&D activities based and otherwise based on the Financial Accounting Standards Board (FASB) Accounting Standards Codification (ASC). The R&D activities include

"a. Laboratory research aimed at discovery of new knowledge
b. Searching for applications of new research findings or other knowledge
c. Conceptual formulation and design of possible product or process alternatives
d. Testing in search for or evaluation of product or process alternatives
e. Modification of the formulation or design of a product or process
f. Design, construction, and testing of preproduction prototypes and models
g. Design of tools, jigs, molds, and dies involving new technology
h. Design, construction, and operation of a pilot plant that is not of a scale economically feasible to the entity for commercial production
i. Engineering activity required to advance the design of a product to the point that it meets specific functional and economic requirements and is ready for manufacture
j. Design and development of tools used to facilitate research and development or components of a product or process that are undergoing research and development activities."

While the following activities would typically not be considered R&D:

"a. Engineering follow-through in an early phase of commercial production
b. Quality control during commercial production including routine testing of products
c. Trouble-shooting in connection with break-downs during commercial production
d. Routine, ongoing efforts to refine, enrich, or otherwise improve upon the qualities of an existing product
e. Adaptation of an existing capability to a particular requirement or customer's need as part of a continuing commercial activity
f. Seasonal or other periodic design changes to existing products
g. Routine design of tools, jigs, molds, and dies
h. Activity, including design and construction engineering, related to the construction, relocation, rearrangement, or start-up of facilities or equipment other than the following:
i. Legal work in connection with patent applications or litigation, and the sale or licensing of patents."

Table 1.1 Characteristics of basic, applied research, and R&D.

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

Comparison

The differences between three types of research can be seen in each of their goals and objectives. Table 1.1 summarizes the characteristics of the three types of research. Please note these are generalities, there are some exceptions.

It is worth noting that basic research forms the foundation for most applied research and R&D. We should understand the relevance of basic research and use its results to execute applied research and R&D. In fact, there is an overlap

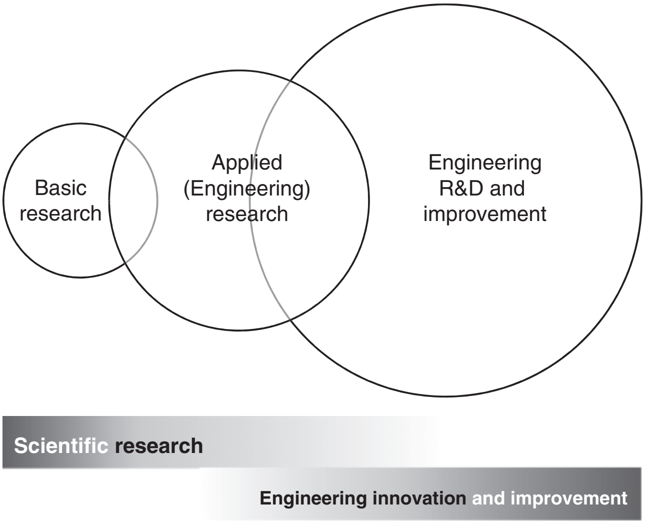

Figure 1.9 Types of research and development.

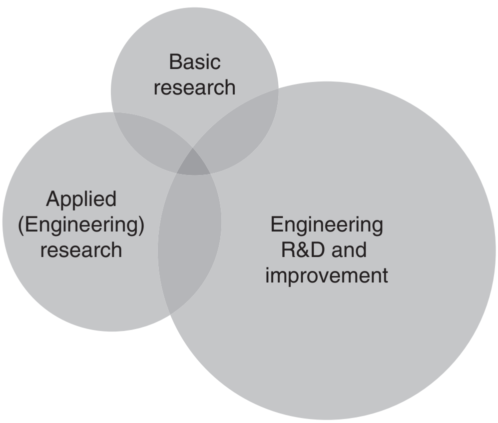

Figure 1.10 Relationship among three types of research.

between two neighboring types. Sometimes, a research project may be viewed a combination of both types, refer to Figure 1.9. In addition, applied research emphasis bridges basic research and R&D.

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.

For R&D, companies who perform internal (funded) research projects for their own development purposes are not bound to any obligation to share learnings from research with society. Depending on the policies, some companies publish their general ideas after implementation. For example, Toyota developed a method to monitor production performance (Roser et al. 2001). They published the method only after having successfully implemented it for years. Another way of sharing the results of industrial development is via patents, which will be more discussed in Chapter 7.

1.3.2 More Discussion on R&D

1.3.2.1 Objectives of Engineering R&D

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.

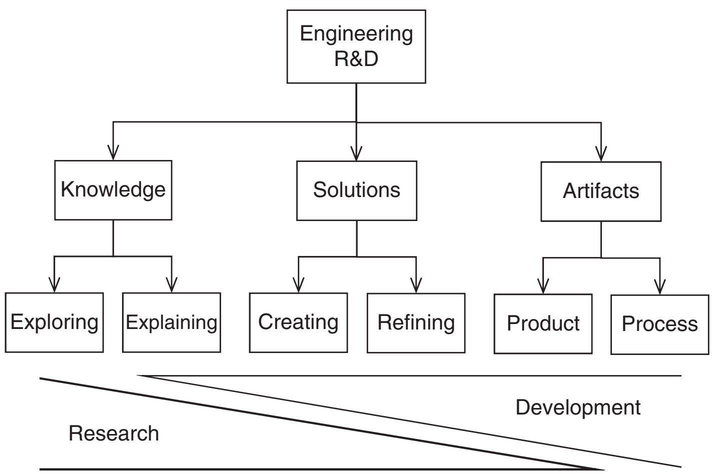

Figure 1.11 Aims and outcomes of engineering R&D.

The contributions to common knowledge from R&D projects may or may not be significant or "revolutionary." For example, a new technological development may only slightly advance contemporary knowledge and understanding questions may be raised about how originality and innovation of R&D is compared with the existing work in order to be qualified as quality research. When doing a comparison, we should include external information if possible because internal results may or may not be sufficient to validate the innovation.

1.3.2.2 Experimental and Empirical Research

Experimental and empirical methods are often used in R&D by directly collecting and analyzing data from experimentations or observations. Other times, indirect data is used as well. Figure 1.12 shows the overall process of experimental and empirical studies.

Note the differences between experimental and empirical studies. In experimental studies, we design and conduct experiments (i.e. manipulating and controlling variables, or designing procedures under certain circumstances). In empirical studies, we observe and collect data from the real world without human manipulation.

We may analyze data quantitatively or qualitatively both in experimental and empirical studies. In addition, there are different ways and methods of collecting and analyzing data for experimental and empirical studies. Based on facts or evidence, the outcomes of such a study are often considered reliable, at least for the particular case defined in a study.

Theory and principles play a guiding role in both experimental and empirical studies. Furthermore, such studies can be used to verify the results based on computer calculation, modeling, and simulation. For example, a thermo-mechanical coupling analysis of transient temperature and rolling resistance for a solid rubber tire is studied by computer simulation and verified by experiments (Li et al. 2018).

1.3.2.3 Descriptive, Exploratory, Analytical, and Predictive Research

Studies can also be categorized into four types to represent their different objectives. Table 1.2 lists these four types of research based on their goals and methods.

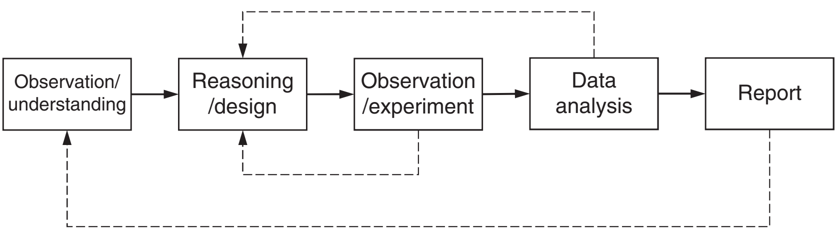

Figure 1.12 A process flow of experimental and empirical research.

Table 1.2 Characteristics of four types of research goals.

	Exploratory	Descriptive	Analytical	Predictive
Goal	To look for a new idea, pattern, or hypotheses	To identify and classify the elements or characteristics of a subject	To explain why or how, to evaluate a subject, and to compare multiple situations	To speculate intelligently on future possibilities, maybe to control
Methods	Observations, literature review, etc.	Often quantitative by observations, case studies, survey, etc.	Often based on the data collected, maybe descriptive	Based on theory and analytical studies
Example	Effects of a new technology	How a new technology affect	Data mining	Artificial intelligence

Exploratory research is to investigate a problem for better understanding, for example, a framework using deep learning constructs to generate mechanical designs (Raina et al. 2019) and an exploratory survey research in engineering ergonomics (Marcos et al. 2018). An exploratory study can be an early phase of a large research project.

Sometimes, research objectives and tasks may be viewed in different orders and levels. For example, analysis is a foundation of prediction. If a future thing can be correctively predicted, then it would mean we have the necessary expertise and tools for mastering of the subject. Figure 1.13 shows the four levels of studies of the overall advance of knowledge, which continuously becomes deeper, closer to the truth, and more difficult to investigate.

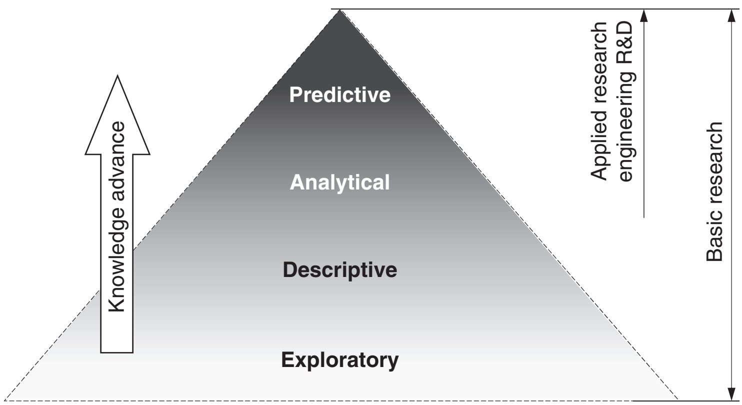

Figure 1.13 Knowledge and skill levels of research.

There is a significant overlap between basic research and applied research in terms of knowledge levels. Applied research projects are often analytical and predictive in nature. Some of them may be associated with descriptive research as well. Therefore, some parts of the four types may be jointly applied in one research project.

1.3.2.4 Case Study

A case study is used to investigate a specific phenomenon or study problem in-depth. Engineering and technical professionals in industries often use a case study as an effective approach to learn about need-to-know situations, such as the causation between input and output, process changing over time, and support for a hypothesis.

In other words, a case study can be practical and result-driven, deemed successful or meaningful only if a particular problem is resolved. Conducting a case study can be an excellent training exercise for student researchers in colleges and new researchers in industry. From a data analysis point of view, case studies can be either qualitative or quantitative, though more frequently the latter than the former. The results from a case study are often descriptive and explanatory.

Below are a few examples of case studies.

> *"Squeezing flow between rigid tilted surfaces: A general solution and case study for MEMS"* (Moy et al. 2017).
> *"A case study on failure of superheater tubes in an industrial power plant"* (Dehnavi et al. 2017).
> *"Effect of misalignments on the tribological performance of elastomeric rod lip seals: Study methodology and case study"* (Pinedo et al. 2017).

Due to their characteristics, case studies have a limitation: the findings from a case may or may not be generalizable or applicable to other situations. However, the procedure and methods used in a case study may have a good reference value for similar applications.

For the same reason, a case study may or may not be considered as research. We may identify a case study as research if it contributes to professional community at large, not only to the organization of doing the case study. Recognizing whether a case study is research can be debatable. A literature review of 31 papers concluded that in case studies can be used for research, but they cannot cover all the hallmarks of science (Josefsson 2016).

Many scholarly journals accept papers of case studies if they have practical significance and/or sufficient technical depth. There are also a few refereed journals dedicated to cases studies, such as

- Case Studies in Thermal Engineering (ISSN: 2214-157X)

- Case Studies in Construction Materials (ISSN: 2214-5095)
- Mathematics-in-Industry Case Studies (ISSN: 1913-4967)

1.4 Validity of Research Results

1.4.1 Research Validity

1.4.1.1 Concept of 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.

One of the important properties of research outcomes, validity is about the soundness and quality of research design, methods, and conclusions and their applicability to similar situations. When addressing the quality of research, we often use the term “validity” and sometimes other similar terms, such as “reliability,” “accuracy,” “objectivity,” “generalizability,” and “credibility” for the same purpose and comparable meanings.

The purpose of validation is to convince readers that the research conclusions are legitimate and justifiable. The evaluation of research validity is based on its contents of measurement and data, analysis and criteria of the data, the methods, and processes used, the reasoning for conclusions, and so on.

There are two types of research validity: internal validity and external validity. Table 1.3 briefly shows a comparison between two types, which will be discussed more in the following subsections.

There are several factors to consider, including the researcher’s personal interests, abilities, assumptions, resources, and ambitions. All these things influence

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

the outcomes of research. Remember, controlling all possible factors that may affect the validity of research is a primary responsibility of the researcher.

1.4.1.2 Internal Validity

The question of internal validity refers to the study itself. In other words, how we logically conduct the research and interpret its results. Another way to think about internal validity is that it helps rule out any alternative explanations in relation to research findings.

A research project and result should "stand on its own," meaning that the methods and process used within the study, such as for obtaining the data, hypothesis testing, and data analysis, are implemented appropriately. The problem statement and supporting tasks should be framed correctly in order to answer the question in a logical sequence.

We may consider research internally valid if its findings accurately represent the data or phenomenon measured and claimed findings. Otherwise, the results may be subjective, incorrect, or even misleading.

The threats to internal validity include the detailed items in study procedures, experimental settings, data collection, analysis methods used, and result interpretation. To evaluate the internal validity of a research project, we may ask a few questions (refer to Table 1.4). Inviting colleagues and friends to ask such questions can be effective and provoke additional thinking. For example, a "maybe" answer to a question indicates a possible issue.

A common issue with internal validity is that researchers do not appropriately monitor or control some variables during a study. These issues due frequently to study design, execution, measurement, or a combination thereof. The resultant findings then, such as a causational relationship, could be questionable due to a problematic process or flawed data. Sometimes, the results from invalid data are not reasonably interpretable.

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?			

One aspect of verifying internal validity is checking whether a particular research is biased in some fashion. For example, we should collect data without the influences from any preconceived outcomes in our mind if any. More importantly, a study should be independent and avoid conflicting factors. The less chance for conflict in a study, the higher its internal validity will be.

1.4.1.3 External Validity

External validity is about the generality of research outcomes or how well results and theories from one setting applicable to another. If the result from a research project is also true for other situations, either by external reviews or by actual tests, it has a good external validity. We may use the terms "generalizability" and "transferability" for the external validity as well.

If a research outcome lacks external validity, we are unable to apply the outcome to a different or larger situations and contexts. In such cases, the usefulness of the research is limited. In research reports and publications, we should acknowledge the limitation in terms of external validity.

Peer-review in a publication process is a common way to check external validity. It is ideal if the same experiments can be replicated by other professionals and yield the same outcomes. To ensure reproducibility, it is important to state clearly the analysis procedure and parameters in the paper and provide the original data in many cases. An example is a study on ignition behavior of a gas turbine (Mansfield and Wooldridge 2014). In the paper, authors provided the data source, "Supplementary data associated with this article can be found, in the online version, at https://dx.doi.org/10.1016/j.combustflame.2014.03.001."

For a laboratory research, we may assess the external validity by asking addition questions listed in Table 1.5.

One example: A new autonomous vehicle had been developed and tested well in a controlled setting. However, it is unknown if the car was operated in various real city and highway settings. In other words, without external validity, the research outcomes and conclusions can be challenged as to whether they "hold up" under a larger scope or different circumstances.

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?			

Achieving external validity can be more challenging than internal validity due to various known and unknown variables in the technical world. Even approaching the same problem, different researchers may have different assumptions and/or take a different path for study and validation. Another factor is the secrecy around the innovation of applied research and R&D to allow testing external validity.

Specific to the research in the form of case studies, their value may be on the innovative ideas rather than the results of specific applications. For example, a paper in civil engineering is for building construction projects in South Korea (Cha and Kim 2018). The result may or may not be applicable to non-Korean locations. However, the systematic framework for predicting the performance proposed in the paper may have a good reference value.

1.4.2 Assessment and Advance

To assess and improve validity, it is important to identify and address the possible bias factors influencing the internal and external validities. For example, a researcher should seek, consider, and analyze possible exceptions and contradictory data, which often imply unknown factors in a study. The two tables above can be a good reference. As mentioned, seeking review and feedback from third parties can be very helpful.

1.4.2.1 To Get Validated

For all types of research, we need to evaluate the results before concluding their correctness. One way is to repeat the tasks undertaken, with the same settings, to check for similar results. If the results are reproducible, then it is highly likely the argument is true for the situation (thus proving good internal validity). Another way is to validate an outcome under similar situations outside the scope of the research originally undertaken. If getting consistent results, the research process and results can be applicable to other situations (proving good external validity).

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

The validation process is valuable to engineering research as it often yields and verifies new inventions. For example, the results of some research projects of computer science and engineering include an algorithm, method, process, technique, or device, which may be all called artifacts. In such cases, any type of artifact generated from a research project should be validated before being put into practice

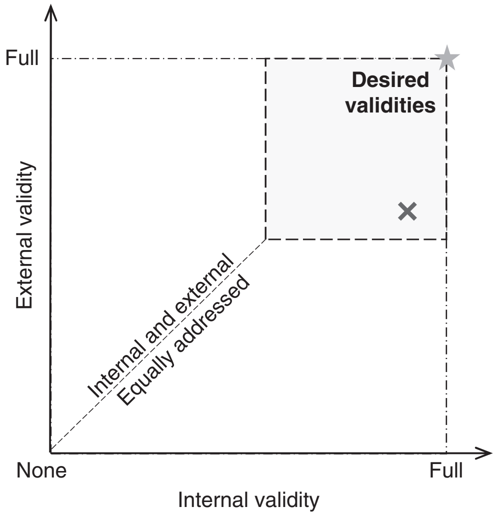

Figure 1.14 Overall validity target of research results.

or manufacturing. A new algorithm must be tested and validated before it is used in commercial software.

An ideal situation is to have research results both fully internally and externally validated, refer to Figure 1.14. It may be difficult to measure validity, but one practical way to evaluate the validity is by dividing criteria to three or five levels, such as poor, good, and full. For example, a computer simulation study, "×" in the figure, may be with good internal validity by a validation using different software and partially external validity by the reviews of domain experts.

1.4.2.2 Considerations of Validities

When we consider the validity of the research, we need to address its internal validity first. The internal validity of research is a foundation to the external validity as it extend a specific claim in a research study to be applicable in other similar situations (refer to Figure 1.15).

In many cases, internal validity is a main concern. Due to physical constraints, such as sample size or time limit, there are often bias factors, which can be any influence and condition that distort the data. For such factors, we should try to avoid them during the design, planning, and execution of a study as much as possible. In addition, we should acknowledge them based on our best knowledge.

Data collection biases include data sampling and measurement errors. Sampling bias can occur due to many known and unknown factors, which leads to nonrepresentative data samples of the entire target population. These potential issues will be discussed more in later chapters.

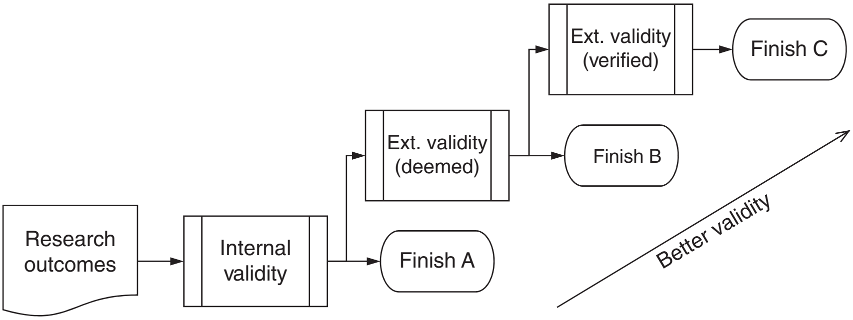

Figure 1.15 Validity levels of research results.

Another factor influencing internal validity of research may be the researchers themselves. The design and execution of a research project can be based on researcher's viewpoints or the methods and process selected by the researcher. The research conclusions can be based on the researcher's subjective interpretations as well.

Due to various reasons, external validation may be constrained or difficult for some cases. For example, research projects performed at for-profit companies and classified operations, such as military or offense projects, attempt to gain a technical or operational advantage. For such research, the validation of the study results may be achieved by putting the idea to practice in various settings "internally." In other words, research results are externally validated inside an organization.

As discussed, research is always done under certain assumptions. The assumptions play a fundamental role on the validities, particularly external validity. If an assumption is only true for a special case, for example, then the research outcome is unlikely applicable to other cases or situations.

When it is needed and feasible, a multiple-case design is a good way to improve external validity. If multiple cases can yield the same conclusions, then they have good generalizability of their findings. In addition, if we design two contrasting cases and the research findings support the contrasted hypothesis, then the results also strengthen their external validity.

Using multiple sources and forms of data is an effective way to reduce potential validity issues related to data. Regarding research methods, two or more methods may be used in a study to check the study results. If different data and/or methods yield the same conclusions, they are very likely valid. This approach is sometimes called triangulation.

1.4.2.3 Publication and Further Development

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.

The findings of some types of research, such as the applied research and R&D conducted in military and industrial corporations, are of good quality but unavailable for publication. Publication is also affected by the policy of a funding agency and the approval process of a research organization. From this perspective, there are different opinions regarding the values of confidential and commercial research to the professional community at large.

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.

Research validity and validation, in terms of the process and criteria, is a research topic itself that is not yet fully explored. Not all research papers are validated before publishing. A literature review showed that 37% of the articles in the field of research in engineering design did not have any validation (Barth et al. 2011). Studying the correlations between types of research and types of validation may lead to more research and the development of a common body of knowledge.

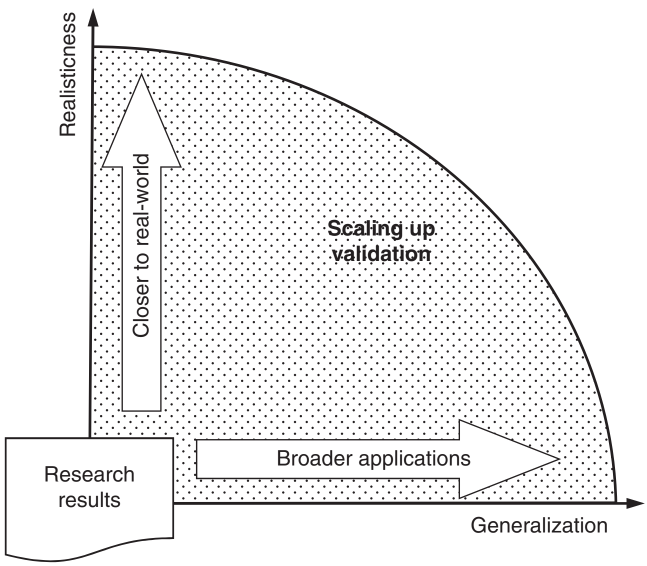

Figure 1.16 Further development of research.

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.

16. Case study is a common format of engineering research – focusing on specific phenomenon or problems.

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.

Exercises

Review Questions

1 What is your definition on research? You may talk about it based on your experience, observation, or just current understanding. (You may save your answer and revisit it when complete this learning.)
2 Find an example that claims doing research but is actually different from scientific research.
3 How to view research from the “know that” and “know how” stand of points?
4 Select an engineering project as an example (e.g. an autonomous vehicle technology) and justify whether it may be considered as scientific research.
5 Think about the basic elements of research and select one to discuss with an example.
6 Explain why some technical efforts (e.g. gathering information and implement a practice from one place to another) may not be considered as research.
7 Based on a published research that you are familiar with, identify three characteristics and discuss why they are important to the research.
8 Explain one personal benefit and one societal benefit from completing a quality research, such as a thesis or dissertation.
9 Ask a critical thinking question to the content of this chapter.

10 Explain the role of critical thinking in research with an example.
11 Discuss the roles and significance of hypothesis in a research project.
12 Based on the discussion, find an example to distinguish methodology and method in research.
13 Explain the differences between basic research, applied research, and R&D with an example for each type of research.
14 Find an example of a type of exploratory, descriptive, analytical, or predictive research.
15 Review the meaning of empirical and experimental research with an example.
16 Find a case study and comment it whether it is considered as research.
17 Explain the significance of research validity with an example.
18 Discuss the differences between internal validity and external validity.
19 Concerning possible high costs and much time required, one might ask what level of internal validity to strive for. What is your perspective?
20 Most master's graduate programs have two options: research and nonresearch (coursework only). Which one you would prefer if the two options were available? Why? (This question could be revisited after completing this learning.)

Mini-Project Topics

1 Search different sources and compare the definitions and meanings of the word "research." In your particular discipline, please provide and justify your opinion which definitions are more appropriate.
2 There is an argument that nonpublishable research due to security reasons is not described as basic research (Thiel 2014). Would you agree? Please explain and justify your claim.
3 In your undergraduate education, master's degree study, or work, select one study and explain its
   (a) Study objectives and procedure
   (b) Principle and method used
   (c) Conclusions and their validity
   (d) What you might like to do if you could do the same study again
4 Locate a research paper related to your current or future interest from your library databases or https://scholar.google.com/, and summarize the paper on its:
   (a) Overall research design
   (b) Data and method used
   (c) Contributions to community or knowledge

5 Interview an experienced researcher and ask the following questions:
   (a) How to find research opportunities
   (b) What methods/tools often used, why select them
   (c) Keys to his/her research success
   (d) Advice to novice researchers
6 Review a research paper on a subject you are knowledgeable from library databases or https://scholar.google.com/, and apply your critical thinking mindset to find the possible future research opportunities.
7 Research work is based on certain assumptions. Find a research work and identify whether the assumptions explicitly stated. Is there any assumption that is not explicitly stated but has some effects in the research results? Use examples to support your answer.
8 Visit the IRB website of your organization or talk with the person who is responsible to the human subjects in research and understand:
   (a) Overall requirements
   (b) Application process and approval
   (c) Required specific training
9 Assume you plan to do a research project at work place or for your degree study, please think about the project and discuss (if you choose a finished project to talk, please also think about how to improve if you could do it again):
   (a) Research objective and problem
   (b) Methods used
   (c) Internal and external validities
   (d) Contribution and impacts
10 Search the different words used in literature but with the similar meaning of research validity. Discuss their same and different focuses compared with word "validity."

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