Thesis Definition and Preparation: Some General Guidelines

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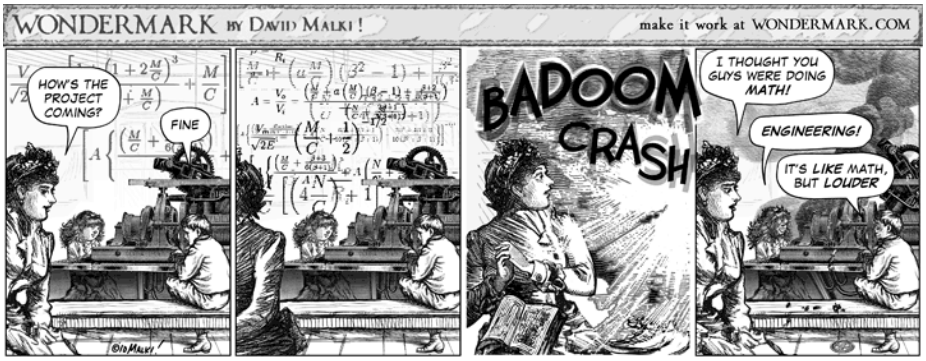

Figure 1: A Wondermark Cartoon: #634; "Accomplishment measured in Decibels." David Malki! June 29, 2010. http://wondermark.com/634/

In the summer of 2010, Professor Dava Newman, then Director of the MIT Technology and Policy Program, asked me to look into updating Professor de Neufville's TPP Thesis Manual. While the document was regularly cited as a guide for ESD graduate students, she recognized that, after twelve years, the document was starting to show its age. Moreover, while some of the questions the manual treats are "eternal," new questions, as well are changed circumstances, have arisen during the intervening years of research and thesis supervision.

Richard was delighted to give me his original materials, and he invited me to "have at it," as it were.

I would have to admit that we each have our idiosyncrasies when it comes to theses,[1] but I have tried to be true to Richard's intent — to give students a set of clear instructions about the fundamentals of thesis preparation.

[1] Footnotes, for example!

Preface

A thesis can be one of the most rewarding, productive experiences of a graduate student's career. As an educational venture it is fundamentally different from the normal classroom experience. It is an opportunity for students to be creative, to bring together and integrate skills they have acquired, to make a real professional contribution. The thesis is a means for students to demonstrate both to themselves and the world that they have achieved a respectable level of professional maturity.

Doing a thesis is also a rare opportunity for a person to concentrate intensely on a professional project they care about, and which they have defined. Many will not have similar experiences again for a long time, if ever. Work after graduation is often spread out over many different projects, and subjected to all kinds of extraneous pressures. The period in which you do your thesis is — whatever it may seem like at the time — relatively sheltered and unpressured. You should appreciate it.

A thesis is often scary. No doubt about it. Many students are initially anxious about how they will manage to complete such a large and demanding project, generally much larger and more challenging than anything they have previously done professionally. Moreover, many naturally suffer from moments of despair along the way as things do not go according to plan. This is natural too.

Many of these thesis crises can be prevented or overcome by appropriate forethought. With the proper guidance, much of the possible pain of doing a thesis can be avoided. This manual presents some guidelines designed to help students execute their thesis expeditiously. These represent both philosophical and practical suggestions concerning issues which have appeared most troublesome to students. They get revised regularly based on comments and suggestions — yours would be most welcome.

Experience validates the usefulness of these guidelines, especially to students who have some latitude in defining their thesis topic. Over 2000 MIT graduate students have tested these recommendations since 1980. Experience also indicates that students doing a thesis benefit from carrying out the exercises in Chapter 12. These explicit exercises represent tasks that all thesis students should in any case be doing, implicitly in their heads if not on paper. They are thus definitely not a waste of time. They provide

opportunities for the thesis student and the advisor to check progress on the thesis and to make mid-course corrections in good time.

Chapter One

Thesis Formulation

The Issue

Most students find it difficult to formulate their research. This is an ordinary phenomenon resulting from the nature of the venture.

This comment deserves emphasis because thesis students in the process of defining their research tend to blame themselves for their apparent lack of progress, and to become discouraged. This negative experience can, however, be avoided by understanding and adopting the right attitude toward the process, and by taking appropriate steps to formulate the thesis. This chapter is designed to help you define your research with a minimum of difficulty.

Formulation of a thesis is inherently challenging because it is research, because it is an exploration into the unknown. Serious research implies a substantial commitment of effort to an activity whose end product is quite uncertain. People would be strange indeed if they did not wonder whether it is worthwhile to invest themselves on some topic whose final value is unclear. Lack of motivation is thus an essential problem.

Just as students cannot anticipate the results of research, they also find it difficult to define the methods and data they should use in the investigation. There should be a close relationship between the means of research and the ends to be accomplished, between the choice of method and data and the kinds of results that can be obtained. For example, a statistical analysis of a series of data inherently generates a description or understanding of average, aggregate behavior. A case study, on the other hand, can illuminate detailed patterns of cause and effect, but does not easily lead to general results. The most appropriate choice of research method depends on the kinds of results you propose to obtain. When possible results are unclear, it can be difficult to choose the right method.

Much of the agony of thesis formulation can be avoided by developing a clearer idea of what you should be looking for: What is a thesis, in fact?

What are its essential elements: How does one formulate research properly?

What is a Thesis?

There is much misunderstanding about the meaning of a thesis. The problem stems from the fact that the physical reality of the form of a thesis — a long document with specific features (abstract, conclusions, bibliography, etc.) — does not define the intellectual significance of the work. This difference between form and substance is confusing. Some people act as if they believe that meeting the superficial attributes of a thesis (length, etc.) will produce a satisfactory thesis. This is not the case, however. There are several classes of professional documents — such as consulting reports — which can have the exterior aspects of a thesis, but not the substance.

A Working Definition

A dictionary definition of a thesis provides a good initial answer. According to Webster's New Collegiate, for example: a thesis is "a proposition that a person advances and offers to maintain by argument." Similarly, the Oxford English Dictionary calls it "[a] proposition laid down or stated, [especially] as a theme to be discussed and proved, or to be maintained against attack."

This definition has three key elements.

1. A thesis is a *proposition*: it advances an idea, a hypothesis or a recommendation;

2. A thesis offers an *argument*: it presents a rationale for accepting the proposition made, rather than simply asserting a point of view; and

3. The argument of the thesis should be *maintained*: it should be made convincingly by appropriate logic and sufficient evidence.

An alternate definition of a thesis is provided by suggesting what is not a thesis. A chronology or other description of a situation is not by itself a thesis (nor is it good history). A straight analysis, for example a large statistical study, is also not a thesis. Nor is an essay expressing a point of view or an opinion. Each of these elements can, of course, be important components of a thesis if properly used to advance and defend an argument.

In short, a good thesis makes a point. It suggests an answer to some issue or question. It attempts to validate that answer.

A Note: The Thesis versus The Research Project

It is important to distinguish between the thesis and the research enterprise that you may have been contributing to during your graduate program.

Embedded in the fabric of the research university is the notion that participation in research is an important component of a student's education. By working with professional researchers, the student learns not only the norms of research practice in a field, but also the norms of academic research itself — how to tease a tractable question, susceptible to formal analysis, from the overall fabric of a broad research inquiry.

Students frequently make the mistake of assuming that everything that they have been working on should be a component of their thesis. This assumption is rarely validated. Much of the work a student conducts in the course of his or her research will be directed toward identifying the question that ultimately becomes the thesis topic, but there will be a lot of mistakes, dead-ends and faulty hypotheses along the way. While documenting these missteps is central to the conduct of research, only those that directly inform the thesis question should be incorporated into the thesis. Remember that your research is more than your thesis, but your thesis should never be about more than the question that you propose to resolve.

Anything more is distracting, if not destructive, to your argument.

Essential Elements

The formulation of a research project, a thesis in particular, should thus address four issues:

- What is the question or issue?
- What method will be used to address this questions?
- What evidence can be applied?
- What logic integrates the above?

A Question

A thesis is helpfully framed as a question that defines the issue under consideration. You may think of it as a hypothesis. For example, the proposition that mediation is a better way to resolve disputes than litigation can be put as a question: "Is mediation a better way to resolve disputes than litigation?"

The idea that a thesis revolves around a question — first put and then answered — must be stressed. Most thesis students do not understand

this at first. Their ideas about long reports typically are based on term papers rather than research. They thus tend to define their thesis in terms of a topic instead of a question. For example, when asked to define their thesis they usually give answers such as: "Development of Cable Communications," "Pricing of Electricity," "Materials Selection in the Automobile Industry," etc. Understandably, the normal first step is to work in an area that interests you. However, the topic does not by itself define a thesis. In each case you need to identify a specific research question within the context of the topic.

The research question must certainly have more than one possible answer. If it cannot be refuted it is a truism of no real interest.[1] For example, the hypothesis "Can Systems Dynamics be Applied to Sustainable Development?" seems to have only one answer — YES. It is hard to see how Systems Dynamics could not be applied somehow. A more challenging hypothesis might be "Is Systems Dynamics more Effective than Macroeconomic Modeling for the Analysis of Sustainable Development?" The answer to this question might be either yes or no, and the research could lead to a surprise, a new insight. This could be worthwhile and interesting.

An Interesting Question

The topic should be worthwhile. You invest considerable effort in your thesis: make it count.

The question you chose for a thesis should be intrinsically interesting. In defining your thesis, ask yourself if the answer to the question has some potential for making a difference. Try to identify what that difference might be, and use this to judge the merit of the thesis.

The question should be interesting to others, at least to some specific audience.[2] From the start, you should anticipate how your effort might help you gain some recognition. Identify the people who would care about the results of your work — and whom you wish to impress. Define their concerns and the problems they feel should be solved. Ask yourself how your thesis could really be of interest to the audience you wish to address.

The question should certainly be interesting to you. If it is not, you will have difficulty sustaining the motivation necessary to get the work done in

[1] You may wish to review the writings of Karl Popper, a philosopher of science who argued that one of the hallmarks of scientific knowledge is that it should be possible to design an experiment whose outcome could disprove, or "falsify," the knowledge. If this experiment cannot be constructed, then the knowledge cannot be called "scientific." Of course, there are other philosophies of science that do not rely upon this notion, but it is a useful one to consider when developing your thesis question. *Popper Selections* (1985, Princeton University Press), edited by David Miller, is a good introduction.

[2] To a certain extent, this goal informs the recommendation that students have research appointments. The existence of an RA position is a reasonably good indication that there is, in fact, a paying audience for questions of the sort you are working on.

a reasonable time.

An Appropriate Method

It is essential to select a research procedure that can lead to answers to the questions you set for yourself. This should be obvious.

Judging by what many student researchers do, however, the need to select a research method appropriate to the question is not obvious, in fact. People often study an issue with some method (a statistical analysis, a case study, an optimization) for tangential reasons. They may be skilled at the method, have convenient computer programs available, or simply fall into it. These factors are not sufficient reasons to select research methods. The critical factor is whether or not your research tools will do the job.

The "Law of the Hammer"

The consequence of not selecting the appropriate method is a lot of work with little significance; the question really is not answered.

Avoid the law of the hammer. Just because you have a specific tool available, do not think it fits all problems. Just because you have a hammer in your hand, do not think you are dealing with a nail. It may be a screw.

Selecting A Method

The process of selecting a research method should focus on the kinds of result each approach can provide, and then address the issue of whether these results could, in fact, answer the question as posed. If they cannot, then either the research method or the question should be altered. Which should be changed depends upon your preferences; the important thing is that method and question be compatible.

Incompatibility between question and method arises frequently when people do a focused study of a particular situation. For example, a student may wish to work on the general question of what the optimum pricing strategy for an industry should be, by studying the experience in the home country or a particular company. Such case studies are systematically unsuited to general questions. It is logically unacceptable to base general propositions on an anecdotal observation of a particular situation. Either the scope of the analysis must be expanded to more cases, or the question must be limited to the specific situation.

Testability of Hypotheses

It is important to understand that many interesting questions do not translate into good research questions or thesis subjects, for the simple reason that no available method is appropriate for answering the question.

For example, the question of whether God exists is interesting to many people, but quite inappropriate for research since there is no method of providing answers to the question. It is a pity that you must exclude many worthwhile questions from your list of thesis topics simply because you will not be able to answer them. Yet, you should face this reality when formulating a thesis, rather than being forced to confront it after having wasted time and effort on an unanswerable question.

In thinking about your method, it helps to be specific. Defining your method in general terms such as "optimization" or "statistical analysis" does not identify enough specifics so that you can estimate either the potential results of the method or its usefulness for your situation. When you think of your method specifically, for example as "linear programming" or "t-test analysis," then you can define the potential result you could get, the kind of data you require, and generally whether the method is suitable for your question.

It is equally essential to select a method that is within your reach. Do you know, or can you learn soon enough, how to carry it out? Will you have the resources — in laboratory supplies, computer time and programs, travel money, etc. — to do so? Before you commit yourself to a specific method, be sure you are confident you will be able to use it successfully.

Evidence

To argue your thesis convincingly, you need to back your assertions with relevant facts. Right from the start you should determine if these are really likely to be available.

Be skeptical about the availability of data. Evidence is often much more difficult to obtain than initial optimism may suggest. As Chapters 4, 5, and 7 indicate, collecting data is generally expensive in terms of money, time and effort.

You may expect many obstacles in gathering evidence. Institutions are typically reluctant to release data. Facts embody some measure of power or advantage: they may help the competition, they may embarrass someone. Many agencies or companies are thus slow to release complete sets of information.

Be wary of uncertain prospects. As advisors, we are always somewhat worried by the following kinds of assertions.

- "The ABC company (agency) is starting something new and I will be able to share their data" — maybe, assuming that the project actually gets going well before the thesis is due — which many do not;

- "I have contacts at ABC, and they have promised to let me see their files" — one student who told me this had to wait an extra year to get

to see the data, and then only in a limited censored version that was virtually useless.

Adopt a fail-safe strategy. It is always best to be sure that the minimum evidence you require already exists or is within your control to obtain. Problems in completing a thesis due to lack of appropriate data are a reflection of a poor thesis formulation. Problems with the availability of data are not a valid excuse for a poor thesis.

Logic

Finally you need to integrate your method and the evidence logically, so that these together constitute a sound logical means to argue your hypothesis. This effort constitutes the "framing" of your question: what way of thinking about the question, your analysis and your evidence will lead to the thesis you want to make?

Ask yourself first of all: What are your criteria for success in establishing your hypothesis? By what measures will you know that you have answered your questions successfully? Then ask yourself what kind of results are in fact likely to emerge from applying your method to the evidence available? Will these results likely be sufficient to make your point? If not, you need to revise either your question or the method, to make them logically compatible. Chapter 8 discusses in detail some ideas about how you may construct a good logical argument and support the point you wish to make in your thesis.

Remember that your logic needs to convince others. The logic used must therefore be adjusted to the audience. For example, if you are trying to make a case for the deregulation of the telephone system, you will need to make a different argument to legislators concerned with the impact of changes, than to economists who already are convinced of the benefits of free markets. Your logic needs to address and surmount the difficulties your audience will have in accepting your results.

Critical Experiments

Research formulated around a "critical experiment" is often particularly effective. For the students, a critical experiment is especially desirable since it leads to a good thesis regardless of how the results turn out. This is because the results will validate one or another of several theories or models.

A critical experiment is one that helps decide between two (or more) competing theories on a subject. The concept is as follows. In general, there are many theories about or models about how a system behaves. People rarely totally agree on how to explain any set of phenomena or observations. All significant theories will account for the major, obvious characteristics of

the subject — otherwise they would not be serious contenders. The several competitive models will differ, however, in that they lead, in some way, to different implications about some particular details. A critical experiment is one that investigates such details to see what happens: depending on the result one (or more) theories are validated (or at least appear more likely) and the others are refuted (to some extent).

Critical experiments are often particularly interesting because the results can be decisive for the validity of competitive theories. They thus tend to attract a lot of attention, which is almost always good for the thesis student or researcher.

To formulate a thesis around critical experiments and evidence, it is necessary to develop a good understanding of the models that are used in an area. This leads to the appreciation of how they differ and what is required to distinguish among them. A thorough, thoughtful literature search, as suggested in Chapter 4, is particularly essential to the formulation of incisive research questions.

Guidelines for Thesis Formulation

The fundamental guideline is that every person formulating a research or thesis topic should consider question, method, evidence and logic simultaneously. These four should all be compatible and feasible. If they are not, the formulation is defective and probably inappropriate. The basic checklist in Exhibit 1.1 provides specific guidance concerning what you need to do to formulate your thesis. It has proven useful for a number of people. Hopefully it will for you too.

1. Question
    - Do you have a hypothesis, a question, or a point to be made about an issue? Note that this is different from a general topic.
    - Is this hypothesis refutable? Does your question potentially have different answers?
    - Who might be interested in the answer to the question?
    - How does this potential audience now understand the issue?
    - How does your question address their concerns?
    - Are you yourself interested in the question?
2. Method
    - What is the proposed method, specifically?
    - Do you already know how to apply this method?
    - Do you have the resources to apply this method: the time to learn it, the equipment or program to carry it out, the money to pay for it?
3. Evidence
    - What kind of data does your method and question require?
    - How much of it do you already have in hand?
    - How sure are you that you will be able to obtain what you require within your deadline? What obstacles might prevent you from obtaining what you need?
    - Will you have a "fail-safe" plan, so that you can complete the work even if you do not get all the data you want?
4. Logic
    - What logic will you use to argue your hypothesis?
    - What kind of results do you expect to get from applying your method to the evidence?
    - What does your audience currently know or believe? What logic will it take to take them from where they are now, to the message you want to leave them with?

Exhibit 1.1: Basic Checklist for Formulation of a Research Topic

Chapter Two

Abstract

An abstract is a short account of the key elements of a thesis, professional paper or report. Its principal purpose is to communicate rapidly the significance of a particular effort.

An abstract is generally easiest to write when the report is done. Then you know what you have accomplished, and what you can summarize.

It is a good discipline, however, to write abstracts both at the beginning and during the progress of the research. You ought to be able to describe to yourself where you are going, how you propose to get there, and why this accomplishment is worthwhile. To the extent you cannot, your research is out of control. That is not a good situation to be in on a major project like a thesis. This observation motivates the discussion of abstracts at the beginning of these guidelines for research.

Length

The length of an abstract should not exceed 200 or 300 words, maximum. Professional media are ordinarily quite strict about the length of the abstract, and you should get in practice. The rationale for the limitation in length is that the abstract loses its purpose if it is too long. Readers scanning dozens of abstracts to find a publication that will interest them are reluctant to read something more than a couple of paragraphs.

Even the most important discovery can be summarized in relatively few words. Anyone having difficulty doing so has not really focused on the important portions of their work. Knowing what your essential contributions are is the key to writing a good abstract.

Title

The title of the work is always associated with an abstract and should be considered an integral part of it. As the abstract itself, the title is part of

your means of communication to potential readers.

The title of a professional report should refer to its key ideas. The title is most useful when it contains the keywords by which you want people to think about your work. Readers often decide whether or not to read an abstract simply by looking at the title. Librarians certainly catalog works largely on the basis of titles. If you provide an inappropriate title you will lose a portion of your potential audience.

Titles that do not describe the subject should be left to literary efforts such as fiction and poetry. Particularly avoid clever titles that amuse you — but confuse the reader. For example, consider the thesis titled "Enlightened Tunnel Visions": what is it about? New discoveries in ophthalmology? Plans for developing mining machines? Some kind of religious experience? Actually, it was an excellent analysis of a system of one-way tolls for the tunnels under Boston harbor — but how would you have guessed? Ambiguities and opaqueness of this type should be avoided. When writing professionally, your objective should be to inform the reader.

Content

After the title has defined the subject matter, the abstract covers the rest of the information required of the summary. This includes:

- The point made by the thesis;
- The method used;
- The evidence presented, together with a brief description of how it was collected;
- The results obtained;
- The conclusions and recommendation; and
- Any special circumstances about the research.

The abstract in Exhibit 2.1 illustrates these guidelines.

Conversely, Exhibit 2.2 provides an example of a less successful abstract. To see its limitations, ask yourself: what does it really tell you? In this case it indicates that someone did a case study about switches that raised issues. Do you now know what the point of the thesis was? Is it, for example to list the issues? To show some generality across areas of high tech trade? That this case is on the contrary different in that it broke new ground? And what method or evidence was used? Is this an econometric study? A case of technology transfer? A political description? The abstract as written leaves too much unclear or unspecified.

Airport Privatisation or Corporatisation?
Lessons from the British Airports Authority Plc and
Recommendations for Kenya Airports Authority

by Philip Wambugu

Many governments, airport owners/managers, and international bodies agree that airports should be run as economic entities. However, there is little agreement on the structure of the ownership/management for airports to accomplish this goal. Some see privatisation as the only hope for the economic rehabilitation of major airports, others prefer the status quo, yet others prefer joint private sector/government ownership or other hybrid solutions. To complicate matters, a policy success in one country may not translate to a similar success in a different country or time. Hence, world governments disagree on which policies to adopt for their airports.

This thesis evaluates the experiences of the successful British Airports Authority plc (BAA) of the United Kingdom; evaluates privatisation and corporatisation policy for Kenyan Airports; and makes recommendations for the administration of the Kenyan Airports using BAA as the reference case and experiences elsewhere, where the question of airport ownership and management is undergoing a metamorphosis.

The main lesson is that BAA's success seems more rooted in the changed operating environment after its corporatisation. In other words, my analysis concludes that privatisation of BAA did not lead to appreciable improvements in its performance. Value based pricing, investment projects, commercially aligned management and clear customer service concerns are striking similarities between the corporatised and the privatised BAA.

Thus for Kenya, corporatisation of airports is recommended considering the difficulties of implementing privatisation in Kenya. This has already been done. However, in addition, the introduction of commercialism in the airports body, strengthening of the manpower base with trained and capable staff, better planning and investment strategies, customer service concerns and freedom on pricing are recommended.

Exhibit 2.1: Example of a Reasonable Abstract, from Wambugu (1992)

The Case of Telecommunications in US Technology Transfer to China

The US and the People's Republic of China have been brought into a closer relationship by a convergence of economic and political forces. Technology transfer from the US to China is an important part of this relationship, serving US economic needs and aiding China's modernization effort.

While both sides benefit from the transfer, domestic and international export controls prevent China's access to the highest levels of our technology. Domestic division exists over whether to increase trade with China or to embargo the 'critical' technologies. International division exists among the allies who disapprove of the US liberalizing trade with China while calling for tighter restrictions on exports to the Soviet Union.

To highlight the issues posed by high technology trade, trading with China, domestic and international export controls, a case study was used. The case involves the sale of ITT digital transit switches to the Chinese government in July of 1983. This case broke new ground in President Reagan's China policy and it was also the test case for stored program control TDMA digital transit switches.

Exhibit 2.2: Example of a Less Successful Abstract

Writing and Abstracts

Some of the basic rules for good expository writing are particularly appropriate when composing an abstract (see also some more general discussions of writing in Chapter 10 and a list of additional resources in Chapter 11):

- Each paragraph should express one main idea — not several;
- Each paragraph should have a front or "lead" sentence that expresses the main idea of the paragraph. A reader should be able to understand the essence of the text simply by reading the first sentence of each paragraph;
- Second and subsequent sentences should develop the idea presented in the "lead sentence."
- The final sentence in the paragraph should bring the idea to a close.

Further guidelines about writing can be found in:

- Bryan A. Garner (2016). *Garner's Modern English Usage*. 4th ed. Oxford, UK: Oxford University Press. ISBN: 978-0-19-538275-1
- Kingsley Amis (1998). *The King's English: A Guide to Modern English*. New York, NY: Thomas Dunne Books
- Jeremy Butterfield (2015). *Fowler's Concise Dictionary of Modern English Usage*. 3rd. Oxford, England: Oxford University Press
- William Strunck Jr. and E. B. White (1999). *The Elements of Style*. 4th. New York, NY: Pearson Longman. ISBN: 978-0205313426

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Amis, Kingsley (1998). *The King's English: A Guide to Modern English*. New York, NY: Thomas Dunne Books.

Butterfield, Jeremy (2015). *Fowler's Concise Dictionary of Modern English Usage*. 3rd. Oxford, England: Oxford University Press.

Garner, Bryan A. (2016). *Garner's Modern English Usage*. 4th ed. Oxford, UK: Oxford University Press. ISBN: 978-0-19-538275-1.

Strunck Jr., William and E. B. White (1999). *The Elements of Style*. 4th. New York, NY: Pearson Longman. ISBN: 978-0205313426.

Wambugu, Philip W. (1992). "Airport Privatisation or Corporatisation? Lessons from the British Airports Authority Plc and Recommendations for Kenya Airports Authority". SM Thesis. Cambridge, MA: Department of Civil and Environmental Engineering, Massachusetts Institute of Technology.

Chapter Three

Time Budgeting as an Element of Research Design

Students writing theses often fail to anticipate the time required to complete their work. They share this problem with many researchers. Students, however, are especially vulnerable because graduation, jobs, vacations and other ambitions depend on finishing the thesis on time.

The pathology becomes apparent when the student realizes towards the expected date of completion that it will be extraordinarily difficult to get the thesis written and approved on time. In the first phase of the syndrome, the student turns into a haggard zombie working desperately round the clock. In the second phase — which afflicts a distressing number of thesis students — one observes canceled graduations, embarrassing inabilities to take up employment at the time promised, substantial added costs of tuition, etc.

These ills are all largely avoidable. The student needs to confront the realities of time budgeting right from the start of the thesis enterprise. The purpose of this chapter is to help you do just that.

More Work Than You Think

A first major error researchers typically commit, concerning time, is to be unrealistic about the total effort required. It is not unusual for thesis students to begin by only spending 5 to 10 hours a week on their thesis at the start of what they plan to be their last semester. To think that this is reasonable is to live in a dream-world.

A master's thesis is the equivalent of two to three full subjects. This implies that a thesis is equivalent to 2 to almost 2½ months of work at 40 hours/week, that is anywhere from 350 to 450 hours of effort (or 1½ to 2 months of 60 hours/week of work.

The simple calculation of the effort required to do a thesis implies that students should start working on their thesis much earlier than commonly believed. This is especially true since the deadlines for these are normally some time before the end of the term. In particular, for a usual Spring deadline in early May, the students should on average be working very intensely on their thesis in February.

Cannot Accelerate Easily

A thesis requires more than just hours of effort; it also requires time for ideas to develop and mature. It's a mistake to think you can do a master's thesis just by putting in a lot of effort during a short period, such as a summer.

A thesis consists of roughly two phases. The first is one of formulation, in which you try out various ideas, meet with potential advisors, investigate sources of data and methods of analysis, etc. This process cannot be compressed easily. Typically, the formulation phase takes about 2 to 3 months of about 5 to 10 hours a week.

The second phase is that of execution of the work. This phase takes 2 to 3 months, but demands at least 25–30 hours a week, if not more.

Schematically, a balanced effort might look something like Figure 3.1. What actually tends to happen to the student who does not look ahead is more like Figure 3.2.

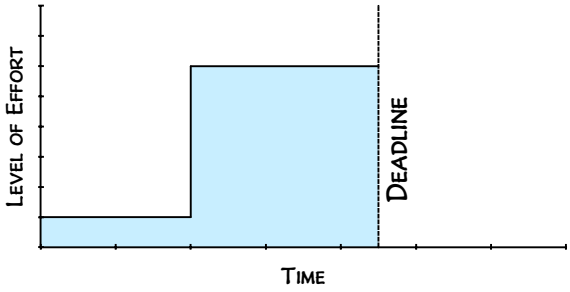

Figure 3.1: A Balanced Allocation of Effort to a Thesis

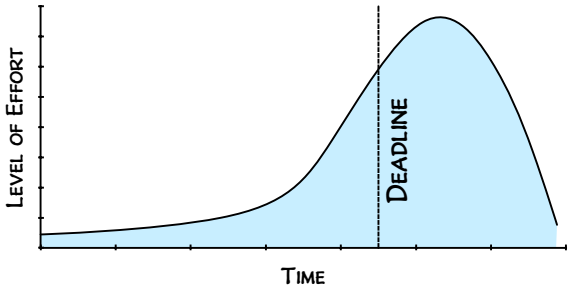

Figure 3.2: A Late and Bad Allocation of Effort to a Thesis

There are External Delays

Another major error most thesis students commit is to forget that the completion of their thesis depends on the cooperation of many other persons and services. These are never available exactly when desired, and least accessible when most needed, towards the deadline. At the same time that you need equipment and services for preparation of your final document, so will everyone else. Your advisor, moreover, cannot be expected to be waiting around with nothing to do, available to read drafts whenever you get these ready. Advisors too will be most busy and least accessible at the end of the academic year, just before graduation. It may easily take your advisor a week to read and comment on any extended draft. Turnaround time from you to advisor and back may easily become a real problem.

To counteract these inherent delays you must plan to have your thesis ready, and thus start working on it in earnest, much earlier than you might imagine. Consider Exhibit 3.1, which projects the time required to finalize the thesis, and then estimates the latest date at which these tasks should be accomplished. In short, to hand in a thesis on time, the bulk of the research must be completed about 1½ months before the deadline!

Naturally, you must also consider that important delays may occur in the research itself: you may have to wait for data to arrive, have difficulty in arranging field visits or appointments, etc.

Activity	Time Required		Example Deadlines		
Turn in thesis		[$T-0$]	May 10	Aug 20	Jan 20
Final word processing, etc.	2 wks	[$T-2$]	Apr 2	Aug 6	Jan 6
Final advisor review	1–2 wks	[$T-3½$]	Apr 15	July 25	Dec 20*
Writing of final draft	2–4 wks	[$T-6½$]	Mar 30	June 30*	Nov 30*

* Remember holidays, when advisors are unlikely to be available. You should add lead time accordingly.

Exhibit 3.1: Typical Working Deadlines needed to meet formal deadline for thesis

Research is Also Iterative

Readers must also bear in mind that research is not a linear process. Because it is a venture into some unknown, because we do not know quite where we are going or how we are going to get there, we cannot expect to get there in a straight shot. Research definitely does not consist of marching through a series of steps directly from formulation to conclusion.

Research is typically iterative. Experienced investigators quite usually start off with a trial solution, use exploratory data and analyses to see how

things work out and then — having learned what seems to work and what does not — proceed to repeat their analyses in detail. It is quite normal to test out a method of investigation, execute a study, and then to replicate it somehow by way of verification.

You will find that something similar is appropriate for your thesis — or will be imposed on you by your advisors. It is entirely possible, if not most likely, that your first drafts will require substantial revision. Experienced professionals writing for journals routinely are required to carry out at least one set of revisions, as can be verified by reading the fine print at the bottom of the first page of most journal articles. You may expect the same.

You will be severely mistaken if you assume that you can write a chapter definitively early on in the process of doing the thesis. The fact is that the content of any chapter should reflect both the results you have achieved and the logic of the argument you will use to make your point. As these elements only become clear towards the end of the research, only then can you correctly finalize each of the chapters. For example, although you may have a reasonably good idea of the literature for the introduction, your advisor is likely to insist that you expand it or alter its focus as you near completion. In short, allow time and plan for revisions as you proceed.

You can make your time and efforts be much more productive if you recognize the iterative nature of research. You can do this by structuring your work to take advantage of the phenomenon. Thus if you plan to do three case studies, for example, you might consider doing them one after another rather than simultaneously. By doing them in series you can profit from lessons learned earlier, whereas by doing them in parallel you may be repeating the same mistakes unnecessarily.

The net result of these observations is that you should allow plenty of time for iterations on your drafts of the thesis. Do not presume that your polished draft will be reviewed for detail only and can quickly be revised. It may come back with suggestions that imply major rewrites if not rethinking. Allow time for this to occur.

The point of this chapter is that you owe it to yourself to plan your time carefully, and to start early.

Methods for Planning Your Time

The section presents three standard approaches for helping you plan and schedule your time. These are: scheduler, bar graphs of the level of effort over time, and the Critical Path Method (CPM). These methods can be executed on a variety of programs available for personal computers.

Scheduler: A scheduler/calendar program (such as Outlook®, iCal, or Google Calendar) allows you to schedule tasks to specific times, and to display them in many ways.

A Time Chart is a useful supplement to a scheduler. It focuses your attention on the schedule, on when various activities should start and finish. It is also sometimes referred to as a Gantt Chart.

A Time chart is simply a table, with activities listed vertically and time (typically in months) horizontally. For each activity there is a horizontal bar underneath the months during which you will do the activity.

While you can construct such a thing by hand within any spreadsheet tool, you may want to employ more sophisticated project planning tools. While Microsoft Project is available to all MIT students, there is quite a learning curve to climb (and, arguably, it's something of an overkill for most thesis projects!). But, if you need all that power, it remains the standard project planning tool (although, like most such tools, its emphasis is upon coordination across a *team* and, thus, may be clumsy for a one-person project like a thesis). With it, you can lay out the required tasks (and sub-tasks) and their anticipated time requirements and dependencies, generating a full time chart/Gantt chart of your research and associated thesis milestones. There are plenty of alternative tools that can be used for the same purpose — scoping the components of your remaining work against the time constraints of Institute deadlines.

Bar Chart of Level of Effort: This device illustrates the level of effort required for the project at any time. It is simply a histogram showing effort vertically, by week or month horizontally. It is constructed by associating the level of effort (in hours/week, say) for each activity in the time chart. When this has been done for all activities, you can sum vertically to see how well the effort implied by your plan corresponds to the time you actually can devote to your project considering your other obligations and needs (to sleep from time to time, etc.). The bar chart focuses attention on the practical implication of a schedule (if it says you should be working 80 hours/week at some time, watch out! Reschedule!).

A bar chart of level of effort can be easily constructed from a standard spreadsheet program. By arranging the tasks in rows and months in columns, and entering the anticipated effort for any task in any period in the corresponding cell, you can simply sum up the projected level of effort for each period. These results can be graphed or displayed as a bar chart.

Critical Path Method: (CPM) helps you identify crucial elements that could, if delayed, interfere with the target date of completion (and thus with your plans for graduation). One of the advantages of using

a project manager like Microsoft Project or its alternatives is that, with a little effort, you can use the tool to generate a critical path analysis of your thesis project.

The object of CPM is to determine the sequence of activities which requires the longest time from start to finish, the "Critical Path". Knowing the critical path for your effort, you can then determine first whether the project is feasible as defined in the time allotted. If this work is not feasible, the critical path indicates which activities have to be redefined or hurried up so as to shorten the path. The critical path also indicates when each activity in the path must be completed, so that the subsequent activities can be completed in the time remaining. This information helps you adjust your effort if you start falling behind.

The procedure is basically simple. You first have to determine the organization of the overall effort, specifically how it is composed of individual activities. This involves essentially three steps. You must, as illustrated in Exhibit 3.2:

1. Identify the principal activities that must be done to complete the total job. For a thesis, these would be: "identify topic," "get approval of advisor," "obtain data," "analyze data," etc. These constitute the "activity list."
2. Estimate the time required to complete each activity.
3. Determine which activities must precede which others (for example, "obtain data" must come before "analyze data," etc.). This information is the "predecessor list."
4. The computer organizes the activities into their logical sequence on a diagram, drawing arrows between activities which must precede each other.
5. Calculates the time along the several paths formed by these arrows. The longest is the critical path.

If the time implied by the critical path is excessive, you will have to change your schedule if you wish to complete in time. You can do this by reducing the scope of some activities (if not eliminating them completely) so that they will take less time.

A major usefulness of CPM lies in its ability to show a person which activities require most attention, and thus to understand where to put priorities to complete a job (the thesis) on time.

	Activities	Time (weeks)	Predecessor Tasks
1	Organization	7	—
2	Contact data sources	7	1
3	Review literature	7	1
4	Define methodology	1	1
5	Write the introduction	2	3, 4
6	Do and write the technical analysis	4	3
7	Do and write the economic analysis	2	3, 4
8	Do and write the functional analysis	2	7
9	Write conclusions and recommendations	2	5, 6, 8
10	Construct draft thesis	2	9
11	Advisor review	2	10
12	Revise and proof final thesis copy	2	11

Exhibit 3.2: Kind of Data Required for a Critical Path Analysis

Chapter Four

Literature Search and Bibliography

Objectives

A good literature search is basic to effective research. This must be emphasized: A number of students treat the effort rather lightly, thinking that bibliographic work is little more than scholastic pedantry and that, if they must do one, they can adequately create it at the last minute, somewhat after they have written the conclusions. In these ideas they are grossly mistaken.

First of all, you need to do a careful literature search because you need to understand the facts of your topic. You can hardly be effective if you do not have a firm grasp on its reality and context, if you do not appreciate the basic forces at work and see how they have played out in other circumstances. More often than we care to remember, we have seen much hard work trivialized by the fact that the person was working on something that had already been demonstrated to be wrong, and they had not bothered to verify.

You neither want to repeat what others have done, nor to ignore the contributions and data they provide. You should appreciate that many people probably have — somehow and somewhere — been concerned with the same kind of issues as yourself. You need to find out exactly what they have done. It is wasteful to repeat their work instead of moving further on.

Other studies are frequently a source of valuable data for your own analysis, either directly or through some form of reinterpretation. Since the collection of data is typically one of the most time consuming and expensive portions of any research (see Chapter 5), it is really desirable to spend time seeing to what extent data can be found ready-made.

Secondly, you need to understand the theories relevant to your issue. Understanding your field means that you should be familiar with the dif-

ferent ways people view the problem, with the opposing schools of thought. In most areas of research, certainly for all policy and management issues, there exist different if not contradictory theories. For example, physicists debate various theories to explain the relationship between electromagnetism and gravity, automotive engineers argue about the best fuels and power plants, and economists disagree on how to manage the economy. The existence of opposing points of view on a topics is almost a necessary complement to a research question. A question implies uncertainty, differences in ideas about the result. To be most effective, you should carefully understand what the alternative views are on your subject.

There are also various schools of thought concerning methodology. Each discipline and profession is likely to look at the same situation quite differently, emphasizing different aspects of a problem and different methodologies of research. For example, in research on how people choose between products or designs:

- Economists might emphasize price and be inclined to use econometric analysis;
- Psychologists might give priority to cognitive perception and prefer laboratory experiments with human subjects; and
- Engineers might place more importance on performance and be inclined to test the materials.

As a researcher you ought to be familiar with the most significant possible frames of reference that concern your issue, and with the consequent methods to attack it. At the start of your work you, in effect, choose between the alternate pathways. At the end, you will have to deal with the criticisms and arguments that other approaches imply.

To make the point you want to make in your research, to make it well so that it can be appreciated widely, you should be able to explain why your approach is superior to alternative explanations. If you cannot do that, you really have not proven anything.

The short of all this is that a careful literature search is one of the most cost-effective investments you can make of your limited resources.

Finding Material

A good literature search combines two complementary elements: use of collegial advice and systematic searches. Unfortunately, most students do not know how to use either effectively, and tend to get involved in a fairly short-sighted ineffective plodding from reference to reference.

Quality versus quantity is the essential problem in a literature search. Quality is of course what we want. We should be doing the literature search

because it helps us, and we want to uncover those elements that are truly helpful. The other material, the references that do not help us, can be discarded.

Beginners often mistake quantity for quality. Perhaps it is associated with the idea that a bibliography is some kind of gloss that makes a report look good. Perhaps it is because it is easier to collect references indiscriminately than to think hard about them. An anecdote illustrates the situation. I remember a doctoral candidate whom I met on a visit. He pointed proudly to three file drawers full of references and told me that he was almost finished with his thesis because he "had all the data." In fact, he never finished: he apparently did not know how to organize the material, or how to make sense of it.

To obtain a first-rate bibliography, you need to identify the key references, both in your own line of work and in the different approaches to the problem. You need to determine:

- What are best references in the field?
- What are the opposing ideas in the field, and which references explain them best?

Networking is an effective way to find the best references. Consult knowledgeable colleagues or advisors. They have typically been in the area many years and can recall a lot of the important references. A trick here is to consult them not just once but several times. It often takes people a little while to see where you really want to go and to recall the important ideas. To minimize possible aggravation, you should consult their articles to see whom they refer to, and should look at their reading lists for courses if they teach.

Once you get into the library, you should systematically examine a number of key bibliographic references which will point you rapidly to all kinds of material that you might otherwise ignore. First of all there are Abstracts. These volumes, typically issued annually in various fields, try to reference every article on a subject, as defined by keywords. In addition to looking at the special technical abstracts, such as the *Ei Compendex* (`https://www.engineeringvillage.com`) or *IEEE Xplore* (`https://ieeexplore.ieee.org/Xplore/home.jsp`), also consult the *Journal of Economic Literature* (`https://www.aeaweb.org/journals/jel`). (Economists tend to get into everything, especially as regards policy.)

Students will also find it useful to consult online resources that index dissertations and theses. The MIT Libraries have prepared a "libguide" with up-to-date links to the services available to the MIT community at `https://libguides.mit.edu/diss/non-MIT` with links to the ProQuest Dissertations and Theses index (PQDT Global) and ABI/Inform Global, among others. For example, ProQuest states that "ProQuest Dissertations

& Theses (PQDT) Global is the world's most comprehensive collection of dissertations and theses from around the world, offering millions of works from thousands of universities. Each year hundreds of thousands of works are added. Full-text coverage spans from 1743 to the present, with citation coverage dating back to 1637." MIT students can consult it online through the MIT Library system.

Next, look at the National Technical Information Service (NTIS) bibliographic database. Specific instructions for accessing resources, depending on site and current MIT subscriptions, can be accessed via https://classic.ntis.gov/products/ntis-database/. The NTIS Bibliographic Database "is the preeminent resource for accessing the latest research sponsored by the United States and select foreign governments. The Database represents billions of dollars in research. Contents include research reports, computer products, software, video cassettes, audio cassettes and more. The complete electronic file dates back to 1964."

For policy issues, you may find it helpful to refer to the Congressional Record Index of the U.S. Congress (https://www.govinfo.gov/help/cri), which cites legislative hearings held by specialized committees of the Senate and House of Representatives. These typically involve testimony by prominent experts and are a good means to understand different aspects of a policy issue.

The Library Staff

Finally, *do not forget the librarians!* These specialists can be incredibly helpful, particularly when you feel that you have reached a "dead end." Your literature work should not start with these folks, but they can offer invaluable assistance when you are able to present them with specific and focused questions. They are particularly helpful when it comes to deciphering citations from other eras and from fields where abbreviations are the norm. They *really* know their way around a research library and can work wonders when the going gets tough. See their "Ask Us!" web page with lists of resources and ways to reach them at https://libraries.mit.edu/ask/.

A vital resource is the libraries' "Research support" webpage (https://libraries.mit.edu/research-support/). Here you can find a complete list of research guides assembled by the librarians associated with your department or academic program, information about writing and publishing your work, and a number of organizational guides for citation and data management services.

Not only can librarians offer specific help, but they can also help you to learn how to make more effective use of available library resources. Note that the MIT Libraries offer classes and workshops, typically posted through the MIT Libraries Events listing (see https://libraries.mit.

edu/news/events/). The MIT Libraries also offer a large set of specialized RSS feeds, listed at http://news-libraries.mit.edu/blog/rss-feeds/. Please consult the Libraries"News and Events" webpage (https://libraries.mit.edu/news/news/) for more information.

Recording Your Progress

A most important remark for anyone doing a literature search: write down the full reference (including page numbers and other details) of any work you think you might eventually cite. You may think this is unnecessary because you will remember how to find it, but two months later many people find that they have lost track of references. It is aggravating to have to look for everything all over again, especially when you are preparing the final draft of the bibliography and your graduation deadline is only a week away.

Preferably, you should be making use of one of the many bibliographic computer tools that are available today. The industry standard these days, particularly for students working in Microsoft Word or other word processors, seems to be EndNote, a product now owned by Thomson Reuters. You can find out about the product online at http://www.endnote.com. You might alternatively prefer Mendeley (https://www.mendeley.com/reference-management/mendeley-desktop), or Zotero (https://www.zotero.org/).

Students planning to use LaTeX to produce their theses should be learning how to use EndNote to generate BibTeX datasets, or they should be learning to use one of the citation databases that natively work in BibTeX. From personal experience, we can say that BibDesk has served us well, but it is only one among many. Almost any of the tools available can emit BibTeX compatible files that can be used in LaTeX and BibTeX or biblatex.[1] Note also that most online journal resources either offer you direct downloads of BibTeX compatible citations or interface with your Mendeley or Zotero citation databases.

Finally, there are also browser-based tools for collecting information found during Internet searches (although, see the caveats about WWW references below).

[1] For those students planning to use LaTeX, I would also recommend learning how to incorporate a version control system (*e.g.*, Apache Subversion, https://subversion.apache.org/) into your workflow. Because LaTeX, almost by design, leads you toward fragmenting a large writing project into smaller components, investing a little time to develop a mechanism for managing those components (and their revisions) will pay off in the long run.
Update: With the rise of git and associated fragmentation of the version control world, I realize that there are lots of alternatives, so please feel free to use what works best for you!

Most of these citation managers also allow you to add your own notes, as well as to include pointers to online resources or to files stored on your computer. Spending a little time now learning how to make the most of these tools will reward you handsomely as you get deeper into your thesis preparations. The MIT Libraries has an overview and a comparison of some of the available tools. An online comparison of the tools that the Libraries support (and offer training in) can be found at: `https://libguides.mit.edu/cite-write`.

Computer Searches

It is much easier to use a computer to search for a reference than to use physical indexing tools. They are particularly convenient when you can use them remotely, relying upon the WWW's indexing and search tools.[2]

But beware: WWW searches can generate a lot of useless material. They emphasize quantity rather indiscriminately. You need to complement computer searches with some ideas — usefully obtained from experienced colleagues — about which authors or research groups have done the best work, and which journals are likely to have the most relevant and most reputable work.

The MIT Libraries' "Information Navigator" offers up a number of resources that can not only help you with your research, but also have been vetted by the Library staff. Its current URL is `http://libguides.mit.edu/infonav`.

Also, as shocking as it may seem, there are some digital resources that are *not* accessible over the MIT Campus network. Sometimes, you will have to go to one of the libraries to access some of these resources — and you should learn how to make use of Barton, the MIT libraries' catalog (accessible via `https://libraries.mit.edu` under the "Search" menu item) to find such things.[3]

The World Wide Web (WWW)

Be extraordinarily cautious if you find you are planning to offer a uniform resource locator (URL) from the WWW as an authoritative source! The WWW is seductively attractive — and frequently untrustworthy. It is attractive

[2] Learn how to use the MIT virtual private network (VPN) tools for your remote computer — see `https://ist.mit.edu/vpn`. In addition to the security benefits gained when using the VPN when off-campus, journal sites requiring paid subscriptions will also recognize you as a member of the MIT community. Touchstone, the MIT digital credentials platform, is getting better at handling the complexities of networking outside of MIT, but the VPN will help when Touchstone gets lost.

[3] Information on how best to make use of the Institute library searches via BartonPlus can be found at `https://libguides.mit.edu/about-bartonplus`.

because it offers quick, 24-hour, convenient access to pages with statements about every conceivable topic. However, the web is untrustworthy because there is no — repeat no — quality control. Practically anybody can post whatever they want. There is no objective review of most of the material that appears online.

In looking at most of the WWW, you are looking at press releases — or worse. The people posting material on the web want to make themselves or their ideas look good.[4] They can present whatever "facts" they want, can give you only the good news, and have little reason to present opposing ideas fairly, if at all.

The material on the web cannot be double-checked. It is here today and may be gone tomorrow.[5] Its sources can vanish without trace. Worse, proper attribution and authority can be extraordinarily difficult to establish — few webpages embed the necessary metadata and, even when present, it is rarely presented in a fashion that permits third-party authentication of authorship. Newspapers at least are archived and many can be viewed on microfilm. The WWW, however, is a transient source of suggestions — some excellent, others most dubious.

Dangers of Wikipedia!

Students increasingly seem to rely upon Wikipedia (http://www.wikipedia.org/) for information. It is, without question, an extremely convenient resource. However, its reliability as a primary reference source about *anything* is dubious. The Wikipedia community has a long way to go to convince the academic community of its ability to weed out faulty or misleading information. Although some experiments have been encouraging (Ray and Graeff, 2008), analyses like those of Gatto (2016) and Cowley and Hanna (2013) suggest that, at least for now, Wikipedia's content is the result of a complex set of forces and agendas that are incompatible with reliance upon it as an academic source (and, apparently, a fertile field of inquiry in and of itself!).

Moreover, it is important to recognize that, in seeking to emulate an encyclopedia, Wikipedia is not really striving to become a primary research authority. You can certainly use Wikipedia as a starting point, but you should *never* offer it as an authoritative source of information — just as, in a bygone era, you would never present an encyclopedia as an authoritative reference of anything other than the text of the encyclopedia itself (i.e., to cite a quotation from the text).

[4] For a humorous take, see http://wondermark.com/338/.

[5] Although the Internet Archive's "Wayback Machine" (https://archive.org/web/) does afford some small remedy to this problem.

Bibliographic Systems

Many systems of preparing references and bibliographies exist and are "correct" in the sense that they meet acceptable norms of scholarship and are used by journals. But some of these systems turn out to be exasperatingly difficult to prepare in practice. So be careful about your selection. Also, you should acquire a style guide such as Hacker and Sommers (2021) or otherwise have ready access to a reference guide for the main citation styles. The MIT Libraries summarize the major style guides online through their Information Navigator at `http://libguides.mit.edu/content.php?pid=80743&sid=598619`.

The reference system should be easy to use, both for the writer and the reader. Using this simple criterion you should reject several broad categories of reference systems right away, unless they are imposed by the traditional requirements of some journal. You should avoid systems with:

- Footnotes at the bottom of a page. For many people footnotes on the same page are a distraction and break the flow of the main argument. (*Personally, I hate them! – RdN*) Others like them, however[6]

- References by number in the text: Since these numbers do not convey any substantive significance, it is difficult for the author to check in the text if the right reference is cited (What if the author makes an error?). Similarly, the reader cannot easily grasp who is being referred to, but is forced to flip to the back to find the reference.

  It is important to note that there are many proponents of numbered references, correctly pointing out that errors in numbering have been essentially eliminated through the increasing reliance upon computer databases for reference management (e.g., EndNote and its relatives). However, these tools do nothing to eliminate the need to flip back and forth between the text and the bibliography — a necessary action that can impede the author while frustrating the reader. While the future of thesis publication may be electronic, with the concomitant ability to painlessly rely upon hyperlinks to move between the text and the bibliography, that time is not yet upon us.

- References by number in the bibliography: Same remarks as above, plus the fact that any arbitrary numerical organization makes it difficult to find the work of any particular author. Alphabetical orderings are preferable.

[6] I, for example, *like* to find supplemental notes to the text in footnotes — I have never understood the placing of such notes at the end of a text, where they appear out of context. But, like Richard, I prefer to confine all references to the end notes. *Op. cit.* and *ibid.* were never my cup of tea. – FF

- Superscripts: This just makes reading and printing more difficult. The alternative is to give the references in parentheses straight in the text.

Recommended Bibliographic Systems

The system that seems to provide the most useful balance between simplicity, intelligibility and reliability is the "Harvard" method that gives the authors' names in the text. It has several advantages:

- Because it uses names rather than numbers, both the author and the reader can have a direct idea of who is being cited, and if this reference is appropriate.
- The reader will also be able to find references easily in the bibliography.
- References correct for any citation are still correct even if the text is radically rearranged.

(**Note:** The following two sections present Prof. de Neufville's preferred implementation of Harvard-style citations with a bibliography based on elements of the so-called Chicago style. More generally, this document also employs the Harvard citation style, with an APA-style bibliography.)

Students should remember that, with the use of a proper citation manager, almost any reasonable (or unreasonable!) scheme can be implemented. It is more important that the student hew to a style consistent with the relevant field, recognizing that there will always be a tension between the traditional forms and the realities of new sources of material. Many style guides will summarize the main methods (Chicago, APA and MLA), but students are advised to consult with their supervisors and colleagues in their respective fields.

In Text Citation

In the text, the recommended method gives all references parenthetically, to author and year. Unless confusion would result, the citations should come at the end of a sentence; otherwise, they should be at least at the end of a clause. Thus: "To expedite their progress, thesis students should pay careful attention to the guidelines for thesis definition and preparation (Field and de Neufville, 2021)." The parenthetical material giving the reference in the text has specific forms for special conditions. See Exhibit 4.1.

If you refer to:	Form to Use	Example
Several articles by the same author in same year	Alphabetical tag on year	(Clark, 1998a) . . . (Clark, 1998b)
Two authors	Both names	(McCord and de Neufville, 1985)
Many authors	Lead author *et al.*	(Schweppe *et al.*, 1985)
Page numbers for a quote	Page references after year	(Tabors, 1992, pp. 18–20)
The paper directly in a sentence	The author(s) with the year in parens	"Tabors (1992) points out that . . . "

Exhibit 4.1: Ways to Refer to Material

Bibliography

In the bibliography, you should list references alphabetically by first author, exactly as cited in the text. For any particular set of authors the references are chronological, with the more recent references first. Thus:

> . . .
> Marks, D. H. (1990a) . . .
> Marks, D. H. (1990b) . . .
> Marks, D. H. (1989) . . .

The format for the references in the bibliography starts off with the authors by last name, and then initials followed by the data. Thus:

> de Neufville, R., Chin, F., and Rebelo, J. (1973) . . .

For a journal article, the string continues with the article's title (in quotes), the journal's name in italics, the volume number, the issue number, and the pages in the journal. For example:

> Cardin, M.-A, de Neufville, R. and Geltner, D. (2015) "Design Catalogs: A Systematic Approach to Design and Value Flexibility in Engineering Systems" *Systems Engineering*, 18/5, pp. 453—471, DOI: 10.1002/sys.21323,

For a book, the string proceeds with the title in italics, the publisher, and publisher's location. Thus:

de Neufville, R. and Scholtes, S. (2011) *Flexibility in Engineering Design*, MIT Press, Cambridge, MA, USA.

Note that for the United States you should refer to any state by its standard two letter postal abbreviation, in this case NY for New York. If there is a possibility of ambiguity, refer also to country: Birmingham, England or Birmingham, AL (USA).

Government documents require special attention. The overall format should be the same as for other entries, but some particular points should be observed:

- Each official document that is not the responsibility of individuals, should be referred to under the name of the highest authority over the issuing agency. Thus you should cite:

  "United States, Department of Transportation . . . "

  rather than

  "Department of Transportation . . . "

  The purpose of this is to avoid confusion when different governments or portions of government each have agencies with identical names. For example, both the United States and several individual states have "Departments of Transportation".

- Many independent authorities may exist within a nation, for example state governments or independent boards. For instance, you would cite:

  Massachusetts, Department of Transportation . . . "

  or also

  "Port Authority of New York and New Jersey . . . "

  The latter is not, strictly speaking, part of either the US Federal government or the individual state governments.

- Differences should be made between independent branches of the government, specifically between the Congress and the Executive. Thus:

  "United States Congress, House of Representatives . . . "

- When some minor part of the government issued the report, its superior agencies should be listed hierarchically starting with the highest. For example: "United States, Federal Aviation Administration, Next General Air Transportation System,. . . "

References to theses should cite which department or program the work was done for. This is because librarians often file these this way, and thus need the information to retrieve the reference. Thus:

> Duarte, J. P. (2019) "De-Risking Project Finance for Infrastructure Development Through Flexibility in Engineering Design," S. M. Thesis, Technology and Policy Program, Massachusetts Institute of Technology, Cambridge, MA, USA.

If the citation has not been published, then sufficient information ought to be given so a reader can hope to track down the report. For example:

- Lasi, D. and de Neufville, R. (2019) "Project Phasing and Flexibility can reduce risk and increase value of the new Space Launch Complex in the Azores," MIT-Portugal Research Conference, San Miguel, Açores, Sept 30.
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You will also encounter special situations. These can be handled in a number of ways. Stick with the general principles outlined above, and you will be OK.

The Rhetorical Précis

Learning to read articles in your field will be a vitally important research skill. Developing this skill not only requires learning how to find useful articles, but also learning how to think critically about the articles that you find. In many respects, this skill is closely related to learning how to write. Deconstructing an article's argument, therefore, is both a research tool and a learning opportunity.

There is also a real, practical issue: literature research is a process of accumulation. While bibliographic software can help you to manage this accumulation, the notes that you make about the articles you collect will be an important resource when it comes time to prepare your thesis.

The *rhetorical précis* can be a (potentially) useful instrument when both developing and practicing your skills in summarizing and critical thinking. Devised by Margaret Woodworth (1988), the rhetorical précis is a

written summary of an article (or argument) whose form and composition are carefully circumscribed (essentially, a writ[7] of summary).

The structure of the rhetorical précis is composed of four sentences, each of which is sharply defined:

Sentence one — the thesis This sentence is composed of three main elements: the citation for the piece of writing, a verb that connotes the nature of the thesis presented and a clause starting with *that* containing a statement of the author's thesis. Note that this thesis clause may also merit an allusion to the rationale behind the author's thesis, which can be presented in a subordinate clause starting with *because*. One might build such a sentence through the embellishment of the following sentence skeleton:

> In «article title» («year»), «author» [claims/shows/claims/argues/etc.] **that** «thesis of the article» **because** «rationale for the thesis»

Sentence two — the evidence This sentence summarizes the information that is developed in the article that is presented in support of the thesis — what is employed to support the argument that the author presents. Since only a single sentence is allowed, the description is necessarily short, but accuracy should be maintained, and the presentation should be as specific as possible.

One could frame this sentence around answering the question of "what evidence is provided, and how does that evidence support the thesis?"

Sentence three — the purpose This sentence should present the intent of the author in presenting the thesis of the article.

This sentence is, in many respects, the most subjective of all of the components of the précis, primarily because very few articles have only one purpose[8] Tenure, reputation, contract requirements and

[7] A *writ* is a term of art drawn from the English legal system. In old English law, a writ was essentially a letter from an authority (usually the sovereign) that instructed an agent under that authority's jurisdiction to perform a specific task because a specific set of conditions had been met. While many requests for such letters were made, the ones actually awarded were used as models for successive requests — the dawn of bureaucracies and their concomitant "fill-in-the-blank" forms. The term continues to be used in the law today, affording petitioners a basis for requesting specific judicial actions — for example, when making an appeal to the US Supreme Court, one must petition for a *writ of certiorari*. If the writ is awarded, the Supreme Court hears the case; if denied, the Court will not hear the case and the ruling of the lower court stands.

[8] Note also that, as you gain deeper insight into the area of your research, you will also gain a subtler perspective on the author's purpose. Therefore, you should recognize that this sentence, over time, may require significant revision.

other mundane realities will be a part of the author's motivation, but the intent that underlies the framing of the paper's argument will generally be what you want to summarize in this sentence. The sentence should open with a summary of the issue that the author purports to address, followed by a subordinate clause starting with *to* or *in order to* that summarizes what the author intends to achieve through the publication this article.

The author's purpose is ___«article purpose»___ **in order to** «intent of article within the context of issue»___

Remember that the author's thesis and the author's goal are distinct: the thesis answers the *what* questions (as in, "what is this article about") while the intent answers the *why* question (as in, "why did this article get written" or, sometimes, "why was this article submitted (or accepted) for publication?").

Sentence four — the audience The closing sentence of the précis describes the target audience (e.g., the general public, a set of technical specialists, or leading decision-makers; Democrats/Republicans, neocons, independents, etc.). It may also allude to the relationship that that the author has, or strives to create, with this audience (e.g., provoke, antagonize, alienate, attract). Avoid generalities.

Two examples are given in Exhibit 4.2.

In “The Control of Strategic Materials” (1944), Walter Hamilton claims that resource-consuming countries must devise specialized policy instruments for the management of the supply of critical materials because the suppliers of these resources are both limited in number and unlikely to be subject to control by the consuming countries. By comparing and contrasting the traditional forms of action employed by businesses and governments, respectively, the author shows that there are critical limits upon action to satisfy national goals when the consumers and suppliers of critical materials are not subjects of a single national government. The author’s intent is to develop a defensible basis for government intervention in the market for resources in order to provide not only political cover for the development of new administrative agencies, but also to challenge policymakers to be more unconventional when considering policy options. This article is directed at free-market economists as well as government policymakers who are confronting the post-World War II political and economic environment.

In “The economics of yield-driven processes” (1999), Roger Bohn and Christian Terweisch argue that firms should explicitly add process yield to other measures of production performance because there are many production technologies whose costs exhibit extraordinary sensitivity to process yield. The authors present a detailed framework for characterizing the consequences of process yield for production economics, and then demonstrate the utility of this framework by applying it to a study of hard disk drive production. The authors seek to extend the analysis of production economics by showing that process yield should be viewed as a strategic variable, rather than as a given characteristic of a production technology. This paper is directed at both the engineering and the manufacturing management communities.

Exhibit 4.2: A Few Sample Précis

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Chapter Five

Data Collection

Purpose

The gathering of evidence is an essential part of research. Evidence constitutes the link between theory and reality. It forces you to translate abstract notions into practical terms and thereby make them useful. Conversely, the confrontation of facts or specific counterexamples with theory enables you to distinguish between correct and incorrect models.

Creative speculation is often crucial to significant advances. For many, it has great appeal as it seems bolder, deeper and more imaginative than detailed, empirical work. Speculation can also be pure fantasy, pointless wanderings from inappropriate premises. Evidence provides the discipline that enables you to distinguish productive and unproductive speculation.

The reason to collect data is thus to determine what is, so that we can match this reality with our models. It is therefore crucial to be careful about our concept of reality: what is a fact? What reality are we trying to define?

Data collection also can be expensive in terms of money, time and effort. Since you inevitably have limited resources, it is therefore important for you to gather valid data efficiently. This task is often far from simple.

Concept of Reality

Facts do not emerge of themselves in any absolute sense. You perceive them through some means of observation: your senses, some mechanical device, or some form of questionnaire. None of these instruments are always perfect. Even when they themselves are flawless, they may be misapplied. Your perception of reality is thus affected by the quality of the instrumentation.

Difficulties with instrumentation and measurement generally can lead to a variety of distinct problems. The following discussion focuses on four

major issues: Reliability, validity, representativeness and significance.

Reliability

Reliability, when associated with measurement, refers to the ability to replicate an observation of a stable phenomenon. Do we get the same answer if we measure something repeatedly? If yes — within tolerable limits — then the measurement is reliable.

Reliability is evidently a most important characteristic of instrumentation. If readings differ significantly each time we use an instrument, or between instruments, or between observers, it is inappropriate to have faith in the results. An essential part of the development of instrumentation is the determination of the conditions that lead to reliable results. Whether we are observing temperature or unemployment rates, we require means of observation (that is, instruments) that are reliable. (Note that the word "instrument" denotes not only devices for measuring physical phenomena, such as a spectrometer, but also devices for measuring social phenomena, such as questionnaires.) Reliability is the factor that enables us to perceive real changes in the phenomenon observed.

As emphasized in basic physical laboratories, standard conditions (as for temperature and pressure) are required to achieve reliable measurements. The standard conditions must of course be relevant to the nature of the phenomenon.

Questionnaires or interviews are notoriously unreliable unless controls are applied rigorously. The personal relationship between the persons involved may easily distort the responses and lead to quite unreliable results. Different observers, or the same observer in different situations, may phrase the questions differently or with a different nuance. The respondent may sense the question differently or may take it more or less seriously.

People who collect data by interview must therefore pay particular attention to standardizing their questions. A good way to do this is by using computer generated or written questionnaires so that the same questions are asked, in the same way and the same sequence, each time. Even if the questioner cannot get the respondent to sit at a keyboard or provide written answers, it is useful to use a predefined questionnaire as the basis for the oral questions.

Validity

Reliability does not guarantee that observations are correct. It is entirely possible to replicate erroneous readings consistently. Instruments are often biased. A scale, for example, may easily be loaded to give inflated readings; a person may be color-blind and systematically fail to observe some colors.

Validity refers to the degree to which a measurement provides a correct measure of a phenomenon. It is a concept quite different from reliability. Just as one measurement may be reliable yet not valid, another may be valid but unreliable.

The question of validity is especially problematic for measurements done concerning individuals. People have all kinds of respectable reasons for not revealing or for distorting their feelings. They may begin by thinking that the questions are an invasion of privacy. They may not trust the interviewer not to use the information against them. They may feel embarrassed by their answers (will people think my income too low?). They may not wish to contradict some official position expressed by their superior, or to express some idea that might seem disloyal (can one normally expects many employees to speak ill of a major new product just introduced by a company?) Finally, it is presumptuous to presume that people have thought about the issues that concern the interviewer or know their feelings on a subject.

Validity is difficult to determine. How can you know that you are getting the "truth" when all you can observe is some surface feature? How do you know, for example, that a person's response reflects their true feelings? In this validity is quite different from reliability, which can be judged by replication. To increase the probability of obtaining valid measurements interviewers should, at a minimum, use a spectrum of tactics:

- Trial questionnaires used with trusting collaborators with whom the interviewer can discuss the results (see further discussion in section on sampling in this chapter);
- Questions that refer to actions a person can imagine taking (e.g.: "If the election were held today who would you vote for?" as opposed to "How do you feel about the candidates?");
- A variety of questions that probe a person's feelings on a topic in different ways to check for consistency (e.g.: "Do you agree with the Pope's position on abortion?" and "Are you a member of Planned Parenthood?").

Representativeness

As a general rule we are interested in the behavior of a large class of items, for example: the behavior of steel beams, the evolution of stars, the customers' demand for products. Our limited resources only allow us, however, to measure a portion of any large set. The issue is: how do you make sure your limited observations represent the whole?

If your set of observations somehow omits elements of the class with special features, you may get a biased reading on the behavior of the class.

For example, if you wanted to know how people liked a new product, you should not only ask people who bought the product — if you did so you would omit the people who disliked it or couldn't afford it, and would miss their reactions. You must therefore be concerned with whether the items you observe are a reasonable cross-section of the class as a whole, with whether they are representative.

The issue particularly arises when you do not know the composition of the class of items in advance, or do not know it in relevant terms. You might then in ignorance omit some elements and obtain biased data. However, if you do indeed know what the different significant components are, you can sample the population efficiently by a variety of means (see discussion of sampling further on in this chapter).

Unrepresentative measurements frequently occur because the plan of the observations, typically designed for convenience, systematically omits aspects of the problem that turn out to have been important. For example, it might seem both reasonable and convenient for the questioner and the respondent to survey airline passengers by a 'random' sample of people waiting in any airport departure lounge. Such a sample would, however, be systematically biased against experienced travelers that tend to arrive at the last minute, and who might reasonably have quite different views on air travel.

To guard against obtaining unrepresentative observations, the designer of the data collection effort should carefully consider:

- Which elements of the population will be systematically omitted from the survey; and
- Whether there are logical or behavioral reasons to believe that these elements are significantly different from those that are sampled.

In any event, the observer should avoid collection strategies based primarily on simplicity and ease of effort. These characteristics themselves may be the source of bias: volunteers for a survey may be extroverts, for example, and thus quite different than the population as a whole.

Significance

Finally, we must be concerned with whether we are asking the right questions. Are we really observing the features of a system that will explain its behavior? The answer here is only obvious if one has a specific model to test.

It is not at all evident that you know what the right questions are when you are in the process of trying to develop a model or theory. As it often occurs that researchers try to develop theory and evidence simultaneously, you may be at somewhat of a loss to know what to do at first. The answer

is neither. Research is iterative. You need to formulate, and reformulate, your research question so that you can be sure you are asking the right questions before you engage in an expensive data collection effort.

Efficiency in Data Collection

You will want to maximize the amount of useful information for your efforts. Conversely, you will want to collect the necessary data as inexpensively as possible. The issue is vital because the time and effort spent to gather data could be very great indeed.

The focus must be on information rather than data itself. Data and information are definitely not the same. The sheer quantity of observations, however reliable, valid, and significant, does not represent the amount of information. The data may be redundant. If five different editions of the daily paper report who won the election yesterday, for example, we have five observations (the editions) but only one piece of information (the result).

Redundancy of observation is useful when the measurements are perceptibly unreliable or when the population being sampled is not homogeneous. The redundancy then defines the distribution of the information.

As a practical matter, the plan for the efficient collection of data include two elements:

- Some arrangement for trial observations of pretests; and
- A sampling strategy.

Pretests

A pretest is simply a small-scale trial effort at collecting data. To the extent possible, it is in all respects like the full effort being contemplated, except that it involves only a small fraction of the effort. It should be part of any serious data collection efforts.

The object of the pretest is to verify that the larger scheme is both practical and useful. Researchers routinely find that their original plan for gathering evidence is unsatisfactory. Many things can go wrong with their original ideas and some almost certainly do. The role of the pretest is to anticipate most of these difficulties so that the researcher can redesign the original plan to avoid initial mistakes, and thus ensure that the data collection is most productive.

A successful pretest requires careful thought. For the reasons described previously, it is not sufficient merely to see if the data collection is feasible or replicable. We must be concerned with validity, representatives and significance.

Two elements improve the likelihood that the pretest will lead to useful redesigns of the data collection effort. One is to have a preliminary theory or model in mind that one is planning to test with the data. Such a model implies some particular responses and results, and data may then be gathered on those. The data collection effort is then certain to be useful, at least to confirm or rebut something specific. If one collects data without a model in mind, one runs the risk of being left with useless, irrelevant statistics.

Secondly, it is helpful to apply the pretest in circumstances that allow you to discuss the results with knowledgeable people. They can help you determine why various things went wrong and how you might correct them. If you use personal interviews, it is important to try to obtain the cooperation of the subjects of the original pretest, so that they themselves can help you redefine the measuring instrument.

Sampling strategy

Sampling strategy consists of devising a plan of observations that maximizes the amount of information for a given number of observations. The efficiency of a sampling strategy is usually defined statistically either by the narrowness of the confidence limits that can be obtained with a given number of observation or, conversely, by the minimum number required to establish prescribed confidence limits.

The most efficient sampling strategies are 'stratified'. These derive from the following facts:

- A heterogeneous population (almost always) consists of different subgroups with various degrees of variance;
- The variance of the entire population is the sum of the variance of each subgroup plus the variance between the subgroups themselves;
- The parameters of the entire population are obtained more efficiently by sampling the subgroups, thereby by-passing the variation between subgroups; and
- The scheme is most efficient if the observations are assigned to each subgroup in accordance to their size and variance.

Many sampling schemes exist. They are tailored according to the types of distributions and the degree of prior knowledge one may have about the population.

As a rule, the more you know about the population in advance, the more efficiently you can design the data collection. This is another reason to use pretests — if you can thereby estimate the distribution of variance of responses in any subgroup, you can increase the efficiency of your information gathering.

There are two main types of stratified sampling schemes: proportional and disproportional. The former simply allocates resources in direct proportion to the size of each subgroup. It is easy and only requires reasonable estimates of the relative size of each subgroup. Disproportional sampling as a rule varies the number of observations in direct proportion to the standard deviation of each subgroup and inverse proportion to the square root of the cost of each observation in that subgroup. This may require quite precise prior knowledge of the situation and is certainly also difficult to apply if you are concerned with many parameters.

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Chapter Six

Modeling

What is Modeling?

The literature of the philosophy of science is full of discussions of what a model is, and what it does. Although there are plenty of open questions that continue to receive serious and ongoing attention, there are some basic ideas that each graduate student should reflect upon.

A Model Is An Idealization Although some models may be quite large and strive to treat some very large systems, a model is a construct that has been devised by a researcher in order to gain some knowledge or insight. As an idealized construct, no model is a complete description of reality.[1] The model is necessarily circumscribed by limits that have been set by the researcher. The researcher may impose these constraints in response to limits of knowledge, limits of the modeling platform or the limits of the class of questions that the researcher seeks to explore.[2]

Modeling is Intentional Models are constructed to achieve certain ends. In research, these ends can be roughly characterized into these three classes (Simon, 1969): (*a*) prediction, (*b*) prescription, and (*c*) validation. In this framework, a *predictive* model seeks to answer the

[1] There's an old joke about the physics general exam question: "Using no more than 200 words, define the universe. Give three examples."

[2] Simon (1990) puts it this way:

> Nature is capable of building, on the scale of microcosms or macrocosms or any scale between, systems whose complexity lies far beyond the reach of our computers and supercomputers, present or prospective. . . .
>
> Modeling, then, calls for some basic principles to manage this complexity. We must separate what is essential from what is dispensable in order to capture in our models a simplified picture of reality which, nevertheless, will allow us to make the inferences that are important to our goals. *[page 7]*

question "what will happen when these conditions are met?" with the strong implication that some (if not all) of these conditions can be brought about through human agency. Essentially, the model seeks to establish/estimate/claim what will result if certain conditions are established? *Prescription* is the reverse: what does it take to get a [desired] outcome? Can the model be used to show what actions need to be taken to ensure that a desired outcome comes to pass? Finally, *validation* is the more general objective: how do things work? What mechanisms make the system behave as it does? How might these insights make it possible to achieve desired outcomes.

Models Are Incomplete and Imperfect Of course, a realistic modeler understands that the intents listed in the preceding section are *aspirational*: the limits of modeling ensure that none of these intentions can be completely satisfied. The goals of modeling are to devise an instrument that can offer insight, rather than to resolve these questions.

Hammond (1996) outlines a framing of analysis that can help students when thinking about the imperfections of their models. He characterizes strategies used to legitimate analytical strategies along a spectrum ranging from tests of "coherence" to tests of "correspondence." A "coherent" framework is one that "coheres" with current theories about the way things work. The ultimate coherence test of an analytical model is whether its derivation can be developed entirely from first principles.[3] At the other extreme are models that cannot be reduced to first principles, but whose behavior "corresponds" to what is observed in the real world.

The development of any model will depend upon combinations of these two tests of "correctness." The extremal cases are rarely useful. A purely coherent model is unlikely to generate results that have any sort of recognizable utility, while a model that corresponds well but does so for no understandable reason can afford only tenuous grounds for action.

Models Shape Perception Because models are idealizations, they are grounded in a set of notions that the modeler hypothesizes are either fundamental elements that can explain observations (i.e., coherent with theories) or are estimated relationships among elements of data sets (i.e., correspond to observations). In either case (or blends of the

[3] Note that the description by Bankes (1993) of consolidative models place them squarely in the domain of "coherent" modeling. Arguably, however, so are his exploratory models — note that, almost by definition, an exploratory model is likely designed according to principles of coherence, while seeking to develop results that "correspond" to that which is, as yet, unexplained.

two), there is a set of hypotheses that forms the core of the model. A good model is one that not only relies upon such hypotheses, but can also be used to test their validity. Unfortunately, it is also very easy to develop a model that merely confirms (or worse, enforces), rather than tests, those hypotheses.

Particularly insidious are the hypotheses that derive from conventional wisdom about the problem at hand. Students should be particularly wary of such hypotheses, particularly in the policy domain. "Conventional wisdom" is not always wise or even conventional. Sometimes, it is just an easy way to explain away inconvenient subtleties and complexities — "a competitive market ensures the optimal allocation of resources," for example. Assumptions based on conventional wisdom may be difficult to challenge, but that should be no excuse if it turns out the model's behavior is fundamentally tied to such assumptions.

Be particularly wary of metaphor. In many respects, a model of almost any complex system will necessarily rely upon metaphors and other simplifying explanatory tools to help to frame an understanding of a system or of the problem to be confronted. (Consider, for example, the "world-wide web", "intellectual property," the "war on drugs," or "urban decay.")

It has been suggested that metaphors not only can be used to develop analogies that deepen one's intuition, but they can also serve as a goad to deeper understanding as one probes the limits of the analogy. However, it is also important to recognize that these metaphors can also prematurely narrow the scope of inquiry by implicitly constraining the framing of problems to match the preconceptions implicit in such metaphors. (See, for example, the discussion of "generative" metaphor in Schön (1993).)

This feature of metaphor (taken, perhaps, to its extreme by Cartwright (1997)) should remind students to be cautious. Models can be powerful tools that can sharpen your understanding of the problem you are studying, but you should remain vigilant against the hazards of becoming overly contented with a model's assumptions and framing.

Modeling as a Component of the Thesis

Many MIT students will find that their research work centers on the development, extension or use of models. By some accounts, modeling is one of the core components of the MIT educational paradigm. Certainly, it is not possible to take any graduate course in the School of Engineering without confronting the notion of modeling and model development.

However, many students find that working on modeling as a component of research can engender a kind of confusion that impedes their thesis work. In my experience, these problems can be avoided, provided the student remembers a few rules:

1. Models are rarely an end unto themselves; rather, they are instruments that are used to achieve an end (see, for example, the discussions in Pielke (2003) and Bankes (1993) on the subject of "consolidative" and "exploratory" modeling).

2. The quality of a model's results is evaluated on multiple criteria, many of which can be derived from the general notions of "coherence" and "correspondence" as articulated in Hammond (1996). However, it is important to note the notion of model validation gets one deep into fundamental issues in the philosophy of science. Some have suggested that the issue of model validation ultimately leads the researcher to an assessment and evaluation of the modeler's intentionality (see, for example, Kleindorfer, O'Neill, and Ganeshan (1998)).

3. Remember that most models don't "do" things; rather, they are the means by which the modeler "does" things. (See "False Agency" in Chapter 10)

4. Probably the most important goal of modeling is the construction of a framework that can be used to conduct communication among those who hold differing viewpoints. In some sense, the ultimate model is one that members of divergent (or even combative) constituencies can understand well enough that it can be used to generate results that are viewed as both credible and acceptable (Churchman, 1973; Little, 1993).

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Chapter Seven

Use of Case Material

One or more case studies may constitute the evidence you will use in your thesis. A case study focuses on a particular example of what could be a much larger collection of similar cases. This detailed examination of a particular situation can take on many forms, such as the:

- Operation of a prototype plant;
- Analysis of data from a particular city, region or country;
- Application of a particular method, etc.

Case studies often prove to be confusing. It is difficult to know what information to collect. Researchers, knowing that a case study by definition requires a detailed understanding of a situation, often get lost in this detail. They may have great difficulty in relating the details to their thesis. Some eventually focus on the detail itself, acting as if that by itself would demonstrate their hypothesis. Others get frustrated by the detail and simply stop collecting it. This issue invariably seems to be: what and how much detail should be included in the case study?

It may be helpful to reframe the components of the thesis when considering this question. In Chapter 1, a thesis was characterized as the presentation of a proposition that is defended using an argument based upon evidence and grounded in logic. Yin (2003) points out that a slightly different framing can help when thinking about the extent and scope of a case presentation. Rather than speaking of the thesis, he speaks of the general components of research design, which are:

1. the research question(s);
2. the proposed resolution of the question(s) [hypothesis];
3. the unit(s) of analysis to be considered in the pursuit of the question(s);
4. the logic that ties the data (evidence) to the proposed resolution(s) of the question(s); and

5. the criteria for interpreting the validity of the findings.

Yin points out that the researcher's choice of the unit of analysis (item #3) is what will define the extent and scope of your "case." While the unit of analysis is a strong function of the question and propositions, remember that it is the evidence required to test your proposition that will shape your choice of the unit of analysis.

Doing a case study well requires you to be clear about the role of this evidence in your thesis. You must know how the information you are assembling will help you maintain your argument. This knowledge defines both the kind and quantity of detail required in the study.

This case study can fulfill many different roles in the logic of your thesis. Each of these has quite different implications for the conduct and nature of the case study. The object of this chapter is to identify the major roles a case study can have, and to indicate how these should shape the study.

In general terms, case studies can either represent applications of existing theory or methods, or be part of the development of such theories. Within each of these two categories there are further possibilities. As these two major alternatives have distinct requirements for the case study, the discussion centers around them.

Application of Theory

Case studies are often applications of a theory or method. They can perform several functions in this way: they may demonstrate a theory, illustrate its use, or simply apply it for some specific purpose.

Demonstration: Case studies often serve to show that a method actually works as intended. This kind of "proof by demonstration" is common in a number of specific fields. In computer science, for example, it is usual to demonstrate a new algorithm or procedure by constructing a program that executes this method. Similarly, James Neely demonstrated his method for evaluation research projects by showing that it performed easily and to the satisfaction of the users in a specific application in the automobile industry (Neely, 1998).

Illustration: A case study can also illustrate a method, process or problem. This kind of application provides the researcher with the opportunity to discuss the strengths and weaknesses of a method, and to indicate the kinds of changes that might be desirable. This is what Luis Paz-Galindo did in his study of electrification strategies for the province of Mendoza (Paz-Galindo, 1997).

Application: The case study may also be a straight application of an approach, done for the results that can be obtained. For example, Ma-

gali Smets applied Dynamic Strategic Planning to the development of the Hibernia Oil Field in the North Atlantic (Smets, 1999).

Implications for Case Studies: The nature of a case study, when it is part of an application of theory, is defined by the requirements of the theory. For a cost-benefit study, for example, one requires data on quantities of effects and on their prices.

In carrying out a case study for application one can thus focus on two simple steps:

1. Identification of the kinds of information required by the method; and
2. Collection of the data required, disregarding other details.

In this kind of situation there should be relatively little question of what kind and how much detail should be assembled.

An interesting aspect of these kinds of case studies is that the data can often be invented by the researcher. For many applications one does not need to know the real situation. For example, if one wants a proof by demonstration, all one requires is a set of data that have the same kind of structure, or complexity, as real problems; one does not need to mimic a particular problem. Likewise, in the use of a method one can input a range of data for any particular parameter and carry out a sensitivity analysis to show what kinds of results would result from different assumptions.

Development of Theory

The preparation of a case study that is intended to help develop and validate a new theory is much more difficult. Case studies that are applications of theory are shaped by the theory being applied. When the theory in question is either vague or non-existent, what can serve as the basis for establishing what an appropriate case study comprises?

The proper approach to the case study depends on the research method used: deductive or inductive. The principles behind each are quite different, and thus have different implications for the case study.

Deductive Approach

The deductive approach starts from some assumptions or known facts and proceeds, by logical deduction, to derive subsequent theories and their implications. It proceeds from the general concept to the particular observations. This approach is also referred to as the Cartesian method, after René Descartes, a seventeenth century French mathematician.

From Yin, 2003, p. 13–14.

1. A case study is an empirical inquiry that
   - investigates a contemporary phenomenon within its real-life context, especially when
   - the boundaries between phenomenon and context are not clearly evident
2. The case study inquiry
   - copes with the technical distinctive situation in which there will be many more variables of interest than data points, and as one result
   - relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result
   - benefits from the prior development of theoretical propositions to guide data collection and analysis

Exhibit 7.1: Robert Yin's Definition of A Case Study as a Research Strategy. The breadth of this characterization should help you to identify how best to structure your case so that your key tests are identifiable and defensible. The more structure you can impose, the more that your case will support a deductive (rather than inductive) approach.

Doing a case study is easier under the deductive than the inductive approach. This is because the deductive approach does start with some sort of theory. This provides specific guidance as to the nature of data that needs to be included in the study.

In this respect the procedure is similar to that for case studies done as applications:

- Define the theory;
- Identify the specific data relevant to its proof; and
- Collect this information.

Inductive Approach

The inductive approach is the opposite of the deductive. It proceeds from the detail to general concepts. The practice here is to collect many different observations, to look for common patterns and thus to enounce general theories. It was the path taken in the main by Darwin in developing his general theory of evolution, for example. This approach is also referred to

Strategy	Form of Research Question	Requires Control of Behavioral Events?	Focuses on Contemporary Events?
Experiment	how, why?	Yes	Yes
Archival analysis	who, what, where, how many, how much?	No	Yes
History	who, what, where, how many, how much?	No	Yes/No
Case study	how, why?	No	Yes

Table 7.1: Relevant Situations for Different Research Strategies. (From Yin, 2003, Fig. 1.1 on p. 5.)

as Baconian, after Francis Bacon, a seventeenth century Englishman and one of the first "modern" scientists.

As case study that purports to examine a situation and to find out what happened is most difficult to carry out successfully. With little or no theory to guide one's efforts to collect data, one is pretty much left to do so indiscriminately. This process is inherently cost-ineffective: much of the material gathered will inevitably turn out to be irrelevant or tangential, so that the effort necessary to gather what one eventually wants is much greater than it would have been if one had started out with a good idea of what one wanted.

Use of a case study as part of an inductive effort is also, to a great extent, a contradiction in terms. The essence of the inductive approach is to draw general conclusions from many particular examples; the essence of a case study is to be unique. Evidently, we do not recommend inductive case studies.[1]

[1]Note: However, students seriously pursuing a case-study based, inductive research program will find that Robert K. Yin presents a thorough introduction to the methodology in *Case Study Research: Design and Methods* (2003).

Limits on Usefulness

The use of a case study as part of an argument to develop or validate a theory suffers from limitations inherent in the unique nature of any case study, and thus unavoidable. These are that:

- A single case study cannot prove a general theory, and it is really a single anecdote; and
- It is always questionable whether the single case study is representative of more general situations.

A single case study cannot prove a general theory, since it cannot demonstrate that there are no counter-examples. The case study can at best corroborate a general theory, and show that it is plausible. This is what Renata Pomponi did in her studies of product design in the aerospace industry (Pomponi, 1998).

The fact that it is extremely difficult to demonstrate that a particular case is representative of a general situation places definite limits on the kinds of conclusions one can draw. Simply put, you cannot expect to go from a single case to a general theory. For example, it is inappropriate to use a single case study of a design process of refineries in Indonesia in the 1990's, to argue a theory about the design problems for all kinds of projects at any period, for all of Indonesia, let alone for all developing countries. Recognize at the start that a single case study can only indicate a possibility. (However, see Flyvbjerg (2006) for some counter-arguments that could be appropriate to your research question.)

A single case study can, however, disprove a general theory. It can be a counter-example, a demonstration that the general theory does not work.

Advantage of Several Cases

It should be obvious that using more than one case as evidence to support a thesis can strengthen the argument. The logic seems compelling: more information means a better understanding. The use of several cases can thus be a critical element of a successful thesis.

Dealing successfully with several cases requires careful thought. The differences between the cases may lead to confusion. This is because the results of each case will inevitably not be identical. For example, the effectiveness of a design process in two companies will be different. In one it might be a success, in the other not. Such a contradiction poses a problem.

If you had only one case, you might have thought — erroneously — that the design process was clearly either successful or not. With two (or more) cases; you cannot tell. To what factor can you ascribe the differences

between the results? To differences in the size of the companies? In their location? Mix of products? Management? You need to consider these inevitable questions before you begin your case studies.

When you plan to do several case studies you need to identify the factors that are most interesting or important. In thinking about a case study of a refinery in Indonesia for example, you would need to decide whether it is most interesting to focus on refineries, on cultural differences, on the effect of size, etc. This choice determines the kind of additional cases you should select.

You should choose complementary cases to span the dimension that is important to you. Thus, if you are interested in the effect of size of a company, your cases should cover the possible range of that factor, from a small company to a large one.

Complementary cases should at the same time be as alike as possible and in the other dimensions. The reason is that when you observe differences between the results of case studies, you want to minimize the possibility that these differences are caused by secondary factors. So, if in your case of an oil refinery in Indonesia you were interested in the effect of size, your complementary cases should concern differently sized oil companies in Indonesia. You would not want to look at different sized companies in different countries, because then you would not know if the differences you observe were due to size or location.

In short, your choice of multiple case studies should mimic laboratory research as closely as practical. You should control for as much as possible while examining differences across the factor of interest.

Choice of Case

A final word concerns the choice of case. It is a warning.

The problem is that many people choose a situation for their case study for emotional or other reasons rather than because of the logic of their thesis. This choice is understandable but often has painful consequences for the research and the thesis.

People easily get caught up in a particular case study. They may be natives of the country, have worked in a particular company or branch of government, or have contacts in a specific situation. These kinds of connections give them confidence with regard to that situation and probably some kind of head start. Fair enough. But these reasons are not intrinsically overwhelming.

Anybody planning to construct a thesis around a case study should resist the temptation to focus their effort on what seems like the easiest place to start. The case study must also be completed and, crucially, must be effective in fulfilling its intended role in the thesis. You must carefully think

through what is needed of the case study, examine alternative possibilities, and then choose. The considered, best choice may happen to be the first one intended. However, the choice that was initially obvious may turn out to be undesirable overall, since the data may prove to be inaccessible (a home country may be quite far away), the company may object to one of its former employees discussing its problems, or the situation itself is too particular, too unrepresentative to provide a good test for a theory you seek to demonstrate.

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Chapter Eight

Construction of an Argument

The ultimate point of the research is to substantiate the thesis. Unfortunately, many fail to communicate their results well, either (a) by being unaware of or (b) by not following some fairly elementary guidelines for justifying their results.

The object of this chapter is to present some of the principles for constructing an argument, and thus to help you do justice to your work.

The General Rule

The general rule is to focus on the overall goal. This has two parts: You need to make the point, and you need to eliminate clutter that hides your message.

Make the point: The presentation — of the whole, of a chapter, or of a figure or table — should be organized around the point to be made. Other organizations are confusing, overly long and, therefore, more difficult to follow. They are generally relatively ineffective.

Eliminate the Extraneous: It is wiser to omit material if it is not especially pertinent. Irrelevant material is not neutral: it is costly and a distraction.

Above all, the thesis is not a lab report covering everything that you have read, thought or done. Much — half or more — of what anyone does in their research turns out to be beside the point. Not to find what you want when you are looking is a natural part of any research process. It is rarely useful to discuss many, if any, of the dead ends your encountered.

Many of the details that you went to much effort to define, and that are surely interesting in some context, will not really be relevant to the argument — the point you finally decide to make. As you

progress in your thesis, you almost certainly shift your topic and redefine its focus, so that much that may seem relevant at the start is no longer useful to the final argument. These details should be dropped from the main text. If absolutely necessary, they can be put into an appendix.

To make your argument well, you need to select what is essential and omit what is tangential. This effort requires a lot of work. Passing from primitive (and ineffective) forms of arrangements — such as an overall account, a chronology, or a description — to a real thesis requires much thought. In a phrase: a good argument is constructed through disciplined editing.

Making the Point

To make your point well, you need to discipline your efforts. You should ask yourself in particular:

- Am I being direct about my argument? Will readers follow me easily? Or is my argument "all there, but disorganized"?
- How does this section (chapter, paragraph, figure, table) help me to make my point? Is it useful or a diversion?

As you present a section, whether it is a chapter, a figure, or a table, it is useful to iterate through the following sequence. A number of variations are possible, but this series captures the essential elements.

Define the point to be made: While it may — should — seem elementary to know why you are doing something, it is constantly amazing to rediscover how often a writer is unable to define the point of even something so simple as a graph. For an extended section, such as a chapter, it is useful to write a paragraph describing what it is you want to say in the chapter. You may not find this easy to do, and that by itself should be revealing: it means that you do not yet really understand what you are writing about. And if you do not, whom can you really expect to understand it?

Define the audience: The nature of the audience you want to reach determines how you can and should present the material. Operationally, you need to decide:

- What premises do you think your audience starts from?
- How do they see the situation?
- What can you take for granted as basis for building your argument?

- What misconceptions have to be removed?

Outline your positive argument: To validate your argument, you need to make both positive and negative arguments. You need, first of all, to show that your evidence does indeed support your thesis — this is the positive argument. Complementarily, you need to show that alternative explanations of your results are inappropriate or less satisfactory — this is the negative argument.

The positive argument is obviously necessary. It also comes naturally to researchers. They are typically immersed in their topic, have gone out to find evidence to support thesis ideas, and know how they will use it to build their case.

A positive argument is not sufficient however. It may be satisfactory to people who want to believe the argument you want to advance, but it will not be enough for skeptics who start with alternative views of your subject. You need to show them that their interpretations do not work as well as yours.

The negative arguments are most important because the skeptics are your prime audience. Although "preaching to the converted" is satisfying — as you can count on a positive response — it accomplishes little in terms of building additional support for your ideas. You will be really successful when you convert the skeptics and change peoples' minds. The skeptics are your target audience, and thus the negative arguments, disproving their preconceptions, are vital to your case.

Edit: As you write, you should constantly review your work and, as you do so, revise the product of the above steps. The development of a good argument requires an iterate process of refinement.

Stasis Theory

A useful rubric that can help you when thinking about the point of your thesis and the arguments you will employ can be taken from *stasis* theory, a rhetorical instrument that has been brought to the technical writing community (see Fahnestock and Secor (1988)).

Formally, each *stasis* is a domain of inquiry within which points of contention might arise when an argument is being made to an audience. As such, they are a guide not only to understanding the core components of your argument, but also to anticipating what your presentation will have to address in order to be convincing. As Fahnestock (1998, p. 345) puts it:

> The practical system of ordered question represented by stasis theory turns out to be a general scheme capable of accounting for the ways issues develop. . . . People inevitably have to be

> convinced that a situation exists before they ask what caused it or move to decisions about whether the situation is good or bad and what should be done about it and by whom.

Fahnestock and Secor suggest technical writers consider each *stasis* question in the following list when constructing their arguments (note that they have amended the questions classical Greek rhetoric to reflect the nature of modern discourse):

1. **Questions of fact** (does your thesis extend, refine, or upset some fact otherwise "known" to be true?),
2. **Questions of definition** (does your thesis suggest that the way in which knowledge of this domain is framed should be refined or reconsidered, or that an alternate construction should be investigated?),
3. **Questions of cause** (does your thesis suggest that current understandings of causality need to be changed, updated, or rethought?),
4. **Questions of value** (does your thesis demonstrate that the importance, relevance, or meaning of something should be revised?), and
5. **Questions of policy** (does your thesis suggest that there are courses of action that should be undertaken or revised?)

Careful consideration of these *stases* when framing your thesis argument can help you to bring your findings into sharper focus and to demonstrate their importance to your audience more effectively.

Timing

You should begin to write up your thesis substantially before you believe that you have finished the research. This apparent paradox is explained by the consistent observation that you will find out, as you prepare your argument, that you have left out some important elements. This revelation will prompt you to continue your research to cover the gaps in your logic you have discovered. Thus, you will in any case have to continue your investigations after you complete your initial draft. You might as well integrate this phenomenon directly into your work plan.

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Fahnestock, Jeanne and Marie Secor (Oct. 1988). "The Stases in Scientific and Literary Argument". In: *Written Communication* 5.4, pp. 427–443. DOI: 10.1177/0741088388005004002.

Chapter Nine

Design of Illustrations

An illustration is any part of the presentation whose main impact is visual: a graph, a figure, a table, a photograph.

Illustrations can be an extremely important part of your argument. On the one hand, they have an immediacy which is powerful ("a picture is worth a thousand words"). On the other hand, many readers will, at least at first, tend to skim a thesis or paper, and retain only a few elements. Good illustrations can reach this element of your audience, as well as reinforce the appreciation of those who will read in depth.

This chapter outlines principles and procedures for the presentation of figures and graphs, work which is notoriously — and needlessly — badly done in practice. These ideas are illustrated by examples. For further guidance, consult:

- Calvin Fisher Schmid (1983). *Statistical Graphics: Design Principles and Practices*. New York, NY: John Wiley & Sons. ISBN: 9780471875253
- Edward R. Tufte (2001). *The Visual Display of Quantitative IInformation*. 2nd. Cheshire, CT: Graphics Press. ISBN: 978-0961392147
- Edward R. Tufte (1997). *Visual Explanations: Images and Quantitives, Evidence and Narrative*. Cheshire, CT: Graphics Press. ISBN: 978-0961392123
- William S. Cleveland (1985). *The Elements of Graphing Data*. Monterey, CA: Wadsworth Advanced Book Program. ISBN: 0-534-03729-1
- William S. Cleveland (1993). *Visualizing Data*. Summit, NJ: Hobart Press. ISBN: 0-9634884-0-6

Principles of Illustrations

Six principles should be kept firmly in mind when preparing any illustration. These are:

1. *The Organization contains half the information:* How the material is presented is as important as what is presented. The organization is the means by which you put the material in perspective. Remember, since as author you are making your own argument, it is up to you to arrange the material so as to make your point most effectively. There is absolutely no need to present the material in the same way as it was displayed in the original source, for example.

2. *Every illustration should have a point.*[1] It should enhance a part of the argument you are making. If it does not, it should be eliminated or placed in the appendix for archival purposes.

3. *There should be only one point per illustration:* More than one is confusing. Use more figures to make different points. Exceptions to this rule are rarely justifiable.

4. *Illustrations should be constructed to make their point:* Extraneous material should be deleted. Key ideas should be given prominent positions. Secondary elements should be kept in the background.

5. *Illustrations should be consistent among themselves:* A sequence of Tables or Figures presenting similar material should be organized similarly. Do not reverse axes, use different units, or reorder columns and rows. Doing any of these will confuse the reader, and probably lead to misunderstandings.

6. *Every illustration should be self-contained:* You should be able to understand it without consulting the text. There are two reasons for this: one is that it makes the illustration much more powerful; the other is that illustrations are frequently seen out of context.

Procedure for Designing Illustrations

The procedure consists of the following steps:

- Determine the point of the illustration: there should be only one;
- Eliminate extraneous material;
- Organize essential material to make the intended point more clearly;
- Label the illustration to explain all elements clearly on the illustration itself; and
- Caption the illustration, indicating the point intended and suggesting key limitations.

[1] **Note:** The working corollary to this principle is that *every illustration should be mentioned in the text of your thesis.*

Application of Procedure

To indicate how the procedure works, it is applied to a badly designed Table from a draft thesis, whose initial version is in Exhibit 9.1. This first version has numerous defects. For one, it is impossible to tell from the illustration what it is about. (It happens to concern a solar energy system.) Secondly, it is not at all evident what the reader is to make of the data. Thirdly, it contains a lot of redundant material (surely it is not necessary to repeat "MWH" 15 times), and absurd meaningless detail (can we really believe that we can measure solar output accurately to six decimal figures, that is, one part in a million?). And so on.

Table XYZ: Single System Analysis—Heat Flow Summary

Collector Sub-system		
Collector Output	1420.87 MWH	
Pipe Loss Forward	17.13 MWH	
Pipe Loss Return	20.38 MWH	
Collector Supply		1383.36 MWH
Storage Sub-System		
Storage Losses	378.89 MWH	
Collector Supply - storage losses		1004.47 MWH
Stored Heat Year End - Year	20.23 MWH	
Beginning Collector and Storage Supply		1024.70 MWH
Auxiliary		
Auxiliary Pump Electric Energy	0.00 MWH	
Auxiliary Heater	1203.94 MWH	
Total Supply		2228.64 MWH
Load		
Dist. Loss Forward	34.73 MWH	
Dist. Loss Return	26.59 MWH	
House load	2167.22 MWH	
Total Load		2228.64 MWH
Ratios		
Collector Supply/Total Load	62.07 percent	
Collector Supply Minus Storage Losses/Total Load	45.07 percent	
Collector and Storage Supply/Total Load	45.98 percent	

Exhibit 9.1: The Table to be revised by the recommended procedure

Determine the point of the illustration: The Table in Exhibit 9.1 contains what seem to be two different kinds of material: some accounting of energy, and a set of ratios. It is not clear how these data relate to each other. For the sake of the example, let us simply agree that the point of the illustration is to show the reader the relative importance of the elements that constitute the energy balance of some solar energy system.

Eliminate Extraneous Material: Much of the material in Exhibit 9.1 is clearly unnecessary for the point to be made. All those repetitions of "MWH" can go, for instance; there must be a simpler way to show this.

Likewise, all those decimal points are meaningless.

Additional material can also be discarded, once we recognize the nature of the data. It refers to measurements of a solar energy system. Measurements on such devices are unlikely to be accurate down to 1%. Consequently, any entry in the Table within that range can surely be taken out, as being within the level of error of the system.

These two sets of eliminations, one obvious and the other based on an understanding of the material, leave us with the simplified table shown in Exhibit 9.2.

Table XYZ: Single System Analysis — Heat Flow Summary

Collector Sub-System		
Collector Output	1421	
Collector Supply		1383
Storage Sub-System		
Storage Losses	379	
Collector Supply Minus Storage Losses	1004	
Collector and Storage Supply		1025
Auxiliary		
Auxiliary Heater	1204	
Total Supply		2229
Load		
House Load	2167	
Total Load		2229
Ratios		
Collector Supply/Total Load	62%	
Collector Supply Minus Storage Losses/Total Load	45	
Collector and Storage Supply/Total Load	46	

Exhibit 9.2: Table stripped of extraneous materials.

Organize Essential Material: Having reduced the original table to its essentials, it becomes clear that it can be reorganized to good effect. First, there is basically one entry per sub-system. There is thus no need for sub-headings. Second, since the table does not say anything about the load, and since it is trivial to state that "energy provided" = "energy used", we can drop the "Load" sub-heading. Third, it now becomes clear that the ratios refer to the proportion of energy provided by the sub-system. These ratios can thus be placed adjacent to a column of data on the absolute energy provided.

Label the Illustrations: The Table now consists of three columns, whose

labels should be clear. One refers to the element that provides the energy, another to the amounts produced, and the third to the proportion produced.

Caption the Illustration: The caption should emphasize the point being made and indicate key limitations. Through the process of elimination and reorganization, the point no longer concerns the "energy balance" of the system, but the contributions of its components. The key limitation is, presumably, that the data apply to a particular design. Exhibit 9.3 presents the final result of the redesign. This version is focused, and to the point. Being simpler, it is easier to understand, and thus makes its point more effectively too.

Every caption should be self-contained and make the point intended by the illustration. It is common practice, in North America certainly, to place captions at the:

- Top, for Tables and Exhibits, and
- Bottom, for Figures and Photographs.

You should construct Tables so as to avoid repetitions in their headings. Use major and minor headings as necessary.

Table XYZ: Contribution of Sub-systems to Total Energy Production for Example Solar Storage System

System Element	Energy Produced (MWH)	Contribution to Total (%)
Collector	1383	62
Storage Losses	-359	-16
Net Collector and storage	1024	46
Auxiliary Heater	1204	54
Total	2228	100

Exhibit 9.3: Final, simpler and more effective version of the Table

A Graph-Based Example

The design principles for illustration apply not only to tables, but also to graphical presentations of information. There are some additional points that should be kept in mind. (See Exhibit 9.4. Details are in Chapter 5 of Kosslyn (2007)).

Consider, for example, Figure 9.1.[2] This figure presents, as a function of the vehicle sales year, the composite curb weight, fuel efficiency, and acceleration performance (expressed as seconds to reach a speed of 60 miles per hour when starting at rest). Considered as a thesis illustration, however, this figure exhibits a number of basic problems.

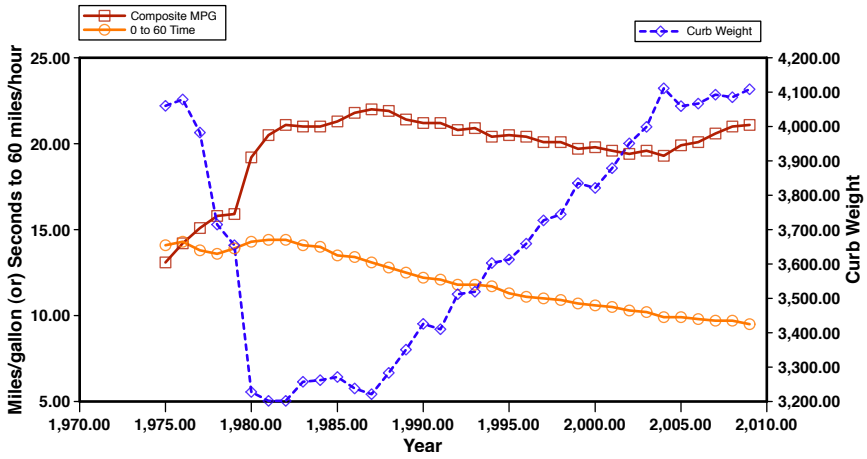

Figure 9.1: US Automobile Sales Fleet Composite Statistics: EPA Miles per gallon, Curb Weight, and Acceleration Time (US Environmental Protection Agency, 2009)

First, from the perspective of extraneous information, consider the axis labels. The two y-axes show two significant digits to the right of the decimal place, but these digits are always "00." The x-axis not only includes these digits, but also employs a "thousands" comma, which is out of place when the number represents a year. Simply cleaning up these simple errors make the figure considerably more legible (Figure 9.2).

Next, there are a few basic norms of graphical representation that should be applied. First, let's re-examine the y-axes. Note that both y-axes cross the x-axis at non-zero values. While the curb weight line would lose considerable resolution if the right-hand y-axis were to start at zero, the Composite MPG and acceleration lines lose little resolution by making this change. Although the right-hand y-axis need not start at zero, the fact that the curb weight line seems to reach (or even cross) the x-axis suggests that the scale should be widened to keep the lines within the graph area.

[2] This example is based on a graphic that can be found in Bandivadekar (2008, p. 63)

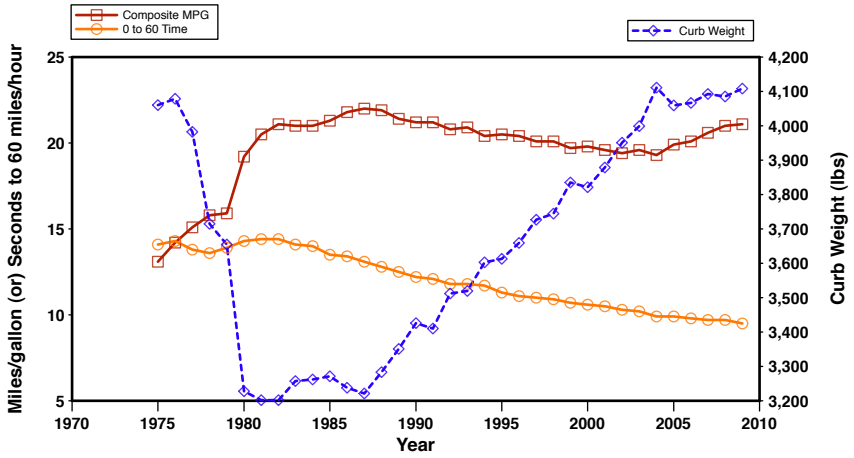

Figure 9.2: US Automobile Sales Fleet Composite Statistics: EPA Miles per gallon, Curb Weight, and Acceleration Time (US Environmental Protection Agency, 2009) [Axis labels edited]

There is also a need to help the viewer read the ups and downs of these data series. While grids can frequently be a source of clutter, the clear intent of this figure is to get the reader to see the relative trends of these these disparate vehicle statistics. The choice of a multiple y-axis figure thus imposes some constraints on the choice of scales, so that the main tic-marks line up. Figure 9.3 shows the resulting figure.

Having cleaned up the graph, let's take a more careful look at Figure 9.3. What message is the creator of this figure trying to impart? The curb

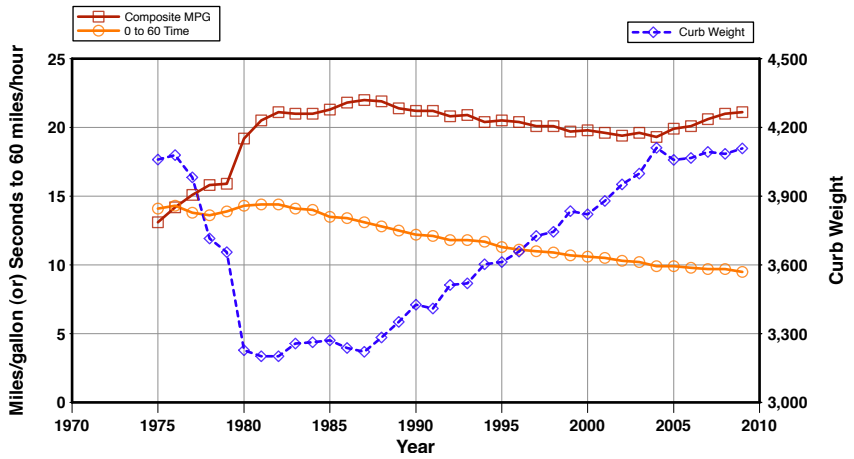

Figure 9.3: US Automobile Sales Fleet Composite Statistics: EPA Miles per gallon, Curb Weight, and Acceleration Time (US Environmental Protection Agency, 2009) [Axis labels and grids edited]

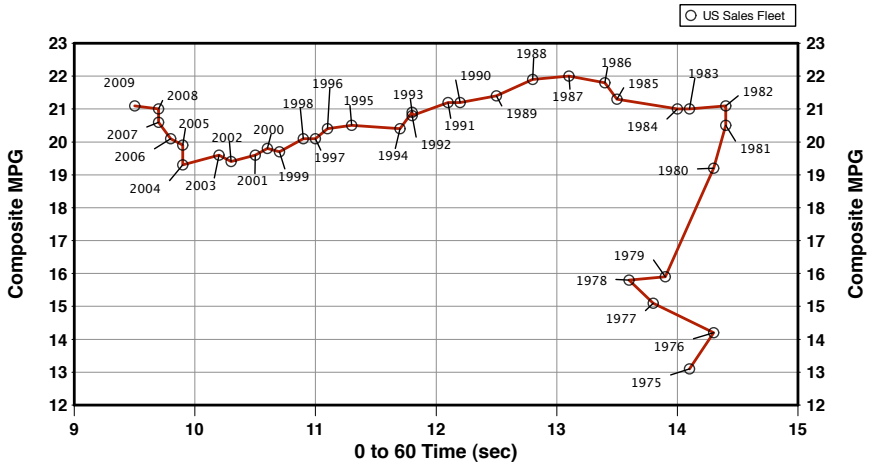

Figure 9.4: US Automobile Sales Fleet Composite Statistics: EPA Miles per gallon and Acceleration Time. Data labels show the model year corresponding to the data point depicted (US Environmental Protection Agency, 2009) [Reconfiguration of data to bring out important difference in performance]

weight curve seems to suggest that automakers worked very hard to reduce the curb weight of their products, leveling off during the early 1980s. Thereafter, the mass of the vehicles has steadily trended upward.

But what do the MPG and acceleration lines tell us? As presented in Figure 9.3, the story seems to be one of relative stability.[3] There's a sharp change in fuel economy in up to the early 1980s (mirroring the drop in curb weight), but thereafter, there doesn't seem to be much to see in this graphic.

However, note what happens if we plot fuel efficiency against acceleration time, as shown in Figure 9.4

Figure 9.4 gives us a completely different way of thinking about the data. The sharp break in the trajectory in the mid-1980s, matching the comparable change in the trend of the curb weight curve, helps to make the message of the data much clearer. The curb weight trends, while important, should be presented in a separate figure.

[3] Kosslyn (2007) describes the source of this mistaken perception, but you can probably guess that it derives from the relative steepness of the curves when presented together like this.

Graphing Semantics

It is vital to remember that a graph is, fundamentally, a *metaphorical* representation of the data used in its construction. The simplest evidence of these representational norms is the fact that that we have named common classes of graphs: the pie chart, the bar chart, the scatter plot, etc. Further, specialized graphing tools have been developed to meet the needs of particular fields (e.g., the open-high-low-close plot from financial markets or the box plot from statistics). In all cases, the utility of these tools depends upon the viewer's familiarity (and facility!) with the metaphors that underlie them.

Students should respect the norms of these tools — hewing to them will repay you with increases in both the efficiency and efficacy of your thesis presentation.

The ubiquity of graphical representations in engineering and science tends to inure students to the metaphors of common graphical forms. Repeated exposure over the course of a student's tenure within a research group can make it all too easy to forget that there is a set of semantic assumptions embedded within every graphical representation. Failure to respect these assumptions can undermine your argument, and drastically derail your presentation.

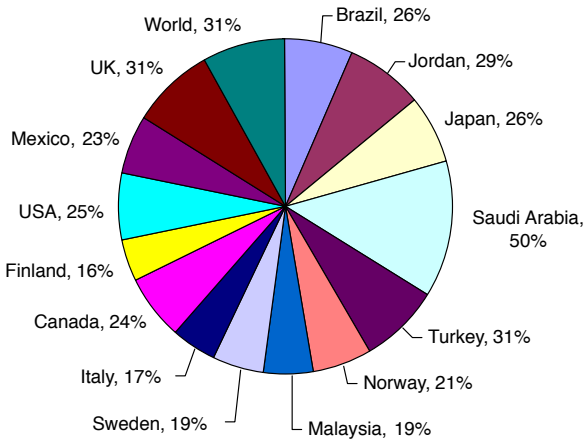

Fig. 1. World wide residential energy consumption (Meyers et al., 2003; Nicola, 2001; Boardman, 2004; Ueno et al., 2006; Araujo et al., 2001; Kamal, 1997; Lenzena et al., 2006).

Figure 9.5: A published example of a graphical data representation that violates the semantics of the selected graph style. From Saidur, Masjuki, and Jamaluddin (2007, p. 1051).

To illustrate the consequences of such a failure, consider the colorful Powerpoint/Excel graphic presented in Figure 9.5[4]. This figure's rationale

[4]Thanks to Randy Kirchain for bringing this example to my attention!

for inclusion is given in the article's opening paragraph:

> Worldwide residential sector consumes about 16–50% of total energy as can be seen in Fig. 1. Energy and exergy analysis is crucial to identify losses, destructions or inefficiencies by the appliances used in this sector so that ways to make improvement or to reduce the losses/inefficiencies can be sought.
>
> — Saidur, Masjuki, and Jamaluddin (2007, p. 1051)

Arguably, the raw data employed to construct this figure supports the article's opening sentence. However, the reader must discard almost every convention of the pie chart in order to find confirmation of the authors' claim in the figure.

Figure 9.5 violates the fundamental intention of the pie chart: *to present the proportional contribution of a complete set of subcomponents to some whole.* (The obvious tip-off: the data labels are given as percentages, yet they do not sum to 100%!) This figure's data series defeats this objective in several ways:

- The data series elements are not additive — they cannot be construed to sum to a whole;
- In fact, the data items are not commensurable — the sum of any two elements is meaningless because the ratios presented do not derive from a common denominator; and
- The data items do not constitute a consistent set of subelements (note the inclusion of 'World").

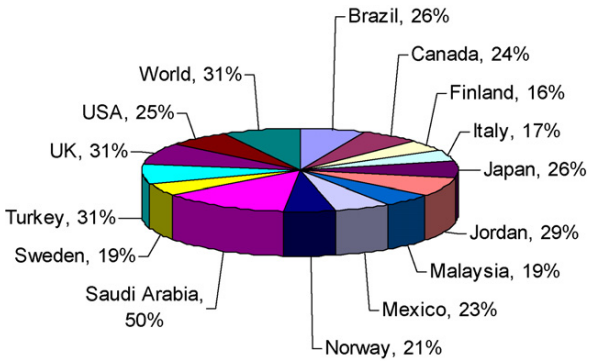

Fig. 1. Worldwide residential energy consumption (adopted from Ref. [2]).

Figure 9.6: How to take a bad chart and make it worse. From Balta, Dincer, and Hepbasli (2010), page 1321.

Arguably, Figure 9.5 constitutes a “perfect storm” of graphical semantic violations. Despite these flaws, the figure was not only accepted for publication in a respected journal, but it has been reproduced in multiple journal articles, with either minor (see Swan and Ugursal (2009, p. 1820)) or major (see Balta, Dincer, and Hepbasli (2010, p. 1321)) modifications. The Balta, Dincer, and Hepbasli (2010) version of the figure merits reproducing here to demonstrate the effectiveness of Excel/Powerpoint “chart junk” at (further) degrading a chart’s meaning (Figure 9.6). Luckily, the authors left the data labels intact.

Eventually, an author (or, perhaps, a reviewer or editor) recognized the deficiencies of the original figure, and a representation whose semantics are more consistent with the data was constructed for Talegheni, Tenpierik, and Dobbelsteen (2012, p. 115).

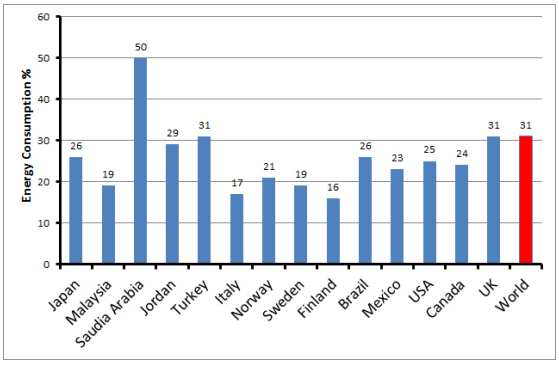

FIGURE 1. Residential energy consumption shown as a percentage of national energy consumption and in relative international form (image after Saidur et al., 2007).

Figure 9.7: A published example of a graphical data representation that is more consistent with selected graph style. From Talegheni, Tenpierik, and Dobbelsteen (2012), page 115.

Note the changes that made this chart more compelling:

- The chosen graph style is specific to the presentation of cross-sectional comparison, without rescaling; and
- Color was used to establish distinctions among the values (note that “World” is a different color than the other bars).

The reader can probably imagine other things that might be done to improve the chart further. For example, the author clearly reordered the data from that presented in the pie chart. However, to what end?[5] One might guess that the goal was to group countries by geographical location, except for the fact that the United Kingdom data point is mis-positioned.

A little effort (see Figures 9.8 & 9.9), even within the confines of Excel, can add useful meaning to almost any data representation. Note that each

[5]Note that both Swan and Ugursal (2009, p. 1820) and Balta, Dincer, and Hepbasli (2010, p. 1321) rather pointlessly elected to reorder the original data series alphabetically.

representation establishes its own point of interest: Figure 9.8 emphasizes the notion of variations within particular regions while Figure 9.9 emphasizes the fact that the Saudi Arabia data point significantly exceeds the global average, while all others are below it.

These distinctions further demonstrate the overall message of this chapter — that your illustration selection and design should go hand-in-hand with the direction and intention of your text.

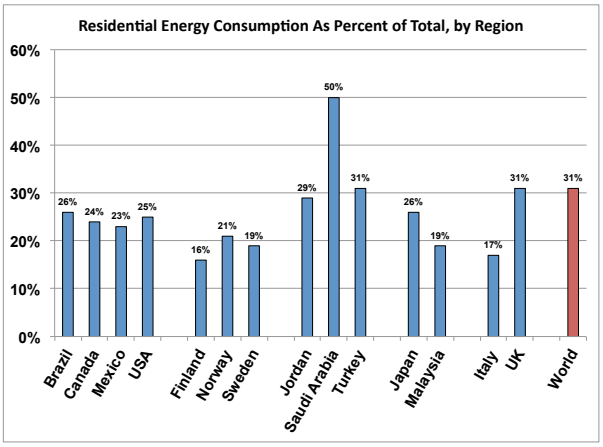

Figure 9.8: A further refinement of Talegheni, Tenpierik, and Dobbelsteen (2012), page 115.

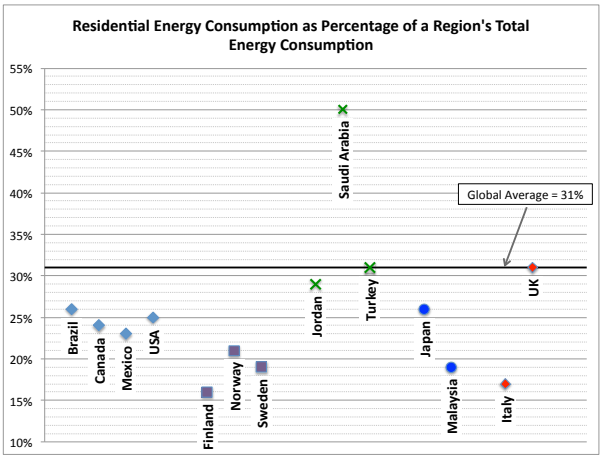

Figure 9.9: Another representation, offering a different look at the data. From Talegheni, Tenpierik, and Dobbelsteen (2012), page 115.

Principle 1: The Principle of Relevance — *Communication is most effective when neither too much nor too little information is presented.*

Principle 2: The Principle of Appropriate Knowledge — *Communication requires prior knowledge of pertinent concepts, jargon, and symbols.*

Principle 3: The Principle of Salience — *Attention is drawn to large perceptible differences.*

Principle 4: The Principle of Discriminability — *Two properties must differ by a large enough proportion or they will not be distinguished.*
Discriminability occurs when we can tell two things apart, whereas salience occurs when differences are so large that attention is involuntarily grabbed by the stand-out object or event. [. . .] Our visual systems register relative proportions, not absolute amounts, so that if a proportion is too small, we won't be able to distinguish between two properties. If a change is not discriminable, it may as well not be there.

Principle 5: The Principle of Perceptual Organization — *People automatically group elements into units, which they then attend to and remember.*
We automatically group together:

- Objects that are near each other. (Compare XXX XXX with XX XX XX)
- Items that appear to be similar. (Consider XXXOOO)
- Objects that line up on a smooth curve. (Consider ——____versus ———)
- Objects that move similarly
- Objects that form simple shapes. (Consider [_] versus _][ )

Principle 6: The Principle of Compatibility — *A message is easiest to understand if its form is compatible with its meaning.*

Principle 7: The Principle of Informative Changes — *People expect changes in properties to carry information.*
Two aspects of this principle are:

1. When we see or hear a change, we expect it to mean something, so every visible or auditory change should convey information. . . .
2. Every change in meaning should be conveyed by a change in appearance. . . .

Principle 8: The Principle of Capacity Limitations — *People have a limited capacity to retain and process information, and so will not understand a message if too much information must be retained or processed.*
Two aspects of this principle are:

1. [A]n audience cannot hold in mind more than four groups of information at once — which I call the *Rule of Four.* But each group can itself contain four groups.
2. Effort is required to search for information or mentally transform information. [. . .] An audience should not have to search through a visual or conceptual haystack to find the needle you are talking about.

Exhibit 9.4: Kosslyn's Eight Principles of Illustration — Quoted from Kosslyn (2007), pages 4–12

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Chapter Ten

Writing Fundamentals for Thesis Scribes

Although a thesis is an opportunity for a student to learn how to construct an argument grounded in academic research, it is also an exercise in writing. And, like almost every exercise in writing, it is an opportunity to improve one's skills in written expression.

One of the most disquieting challenges of thesis supervision is the receipt of a student's lengthy draft that, upon review, leaves the supervisor with the feeling that the only really appropriate comment is "Start over from scratch." Sadly, in our experience, this unhappy recommendation is becoming more common, and we have begun to try to stave off the worst problems through a series of writing exercises for our own research students.

Unfortunately, there is no common strategy that is employed by research supervisors. Many will simply rely upon you to "learn by doing." This chapter summarizes some of our observations about the problems that many students struggle with, and some of our suggested strategies for tackling them.

Every graduate student should learn a writing strategy, and exercise it as frequently as possible.

MIT also offers many resources that can help students with writing.

Expository Writing Style: Basics

A good starting point is the acronym "IMRaD," which stands for "Introduction, Methods, Results, and Discussion" (an "A" is occasionally prepended, signifying the importance of the "Abstract" in most technical writing). This basic style of presentation is most prominently associated with the American Psychological Association's (APA) style guide (Hacker, 2004), and is

known as the "APA style." See, for example, Figure 10.1, which is taken from the APA online tutorial on style for research papers.

Other commonly cited styles are "Chicago," from *The Chicago Manual of Style*, or "MLA," for the Modern Language Association. Many fields have adopted one of these styles as their basis for presentation of not only reports, but also bibliographies, citations and other standards of presentation. While modern word processing tools can limit the damage that a failure to select the appropriate style can engender, it is to your advantage to establish the stylistic expectations of your research supervisor early in your thesis process.[1]

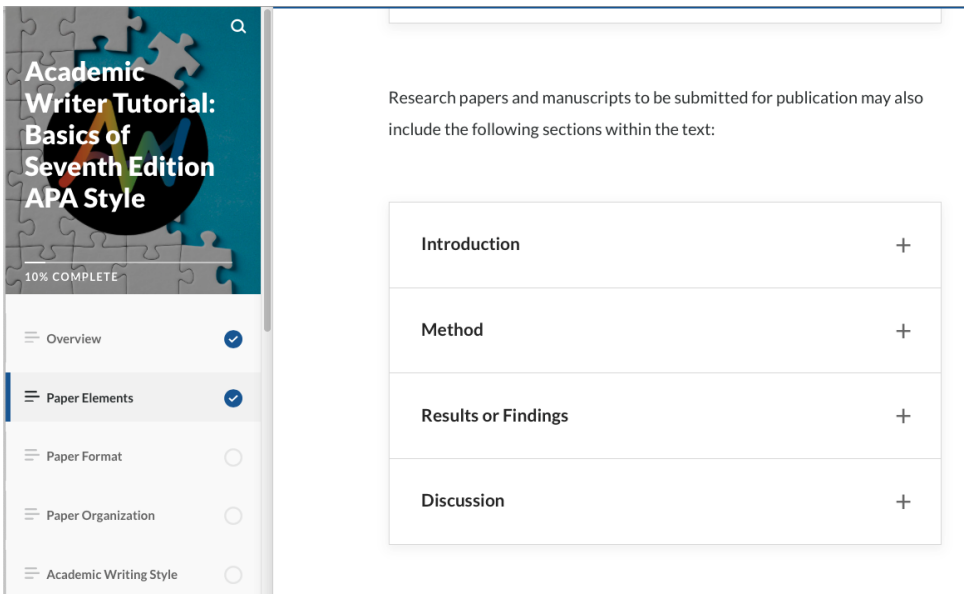

Figure 10.1: From Academic Writer Tutorial: Basics of Seventh Edition APA Style; Section 2: Paper Elements. From `https://extras.apa.org/apastyle/basics-7e/#/`; lastchecked April 20, 2021.

The Principle of Least Astonishment

Although it is a stereotype, the fundamentals of American expository writing can largely be summarized as:

- Tell your reader what you are planning to write about;

[1] Note that MIT publishes its own *Specifications for Thesis Preparation* (MIT Libraries, 2019), and the MIT Libraries also offer pointers to references for the main citation styles (currently at `http://libguides.mit.edu/content.php?pid=80743&sid=598619`).

- Write about it; and
- Summarize for your reader what you just wrote about.

Of course, there is a lot more to it than that, but this simple (and somewhat foolish) list does establish one important feature of technical writing: there should be no surprises.[2] A reader may well believe that your results are unexpected, or that your conclusions contradict conventional wisdom, but the reader will also expect that the author will have prepared the reader for this outcome.

Note that this structure of presentation is not universal. There are traditions that train technical writers to keep the conclusion an open question until essentially the last page (or paragraph!) of a document. Many students who have been trained in these traditions struggle with this difference in style, but success at MIT will be heavily dependent upon learning to adopt this style of technical exposition.

In Language, Tortuous ≠ Academic

A particularly baffling transformation occurs when students start putting words to paper. Students who express themselves clearly when speaking somehow are unable to assemble a direct thought on paper. Somewhere along the way, many students become convinced that a simple declarative sentence is out of place in academic writing. A basic statement like "I tried to put out the fire" becomes "An effort was made to extinguish the fiery conflagration."

While clarity may require the use of an elaborate vocabulary, gratuitous grandiloquence utilizing a polysyllabic lexicon to demonstrate one's erudition instead makes you look vainglorious, pretentious, and naïve.[3]

The Passive Voice

Programmers have used the increasing power of computers to equip word processing programs with a host of useful tools. Many of these tools can help you to improve the quality of your manuscript, but it is important to remember that these instruments are only tools, and that you are responsible for the changes to your text that these programs suggest.[4]

[2] Those of you with computer science backgrounds will recognize the section heading as a design principle for user interface coders. It is also sometimes cited as the "rule of least surprise."

[3] See how that works? It would have been just as easy to say "using unnecessarily fancy words to demonstrate your intelligence will frequently have the opposite effect."

[4] As someone whose research has frequently intersected with the scope of the US Corporate Average Fuel Economy standard for light duty vehicles, I cannot begin to express

While there are many times when these programs' suggestions have merit, I would urge caution when these programs suggest rewriting sentences that are in the passive voice. I often wonder at what must have been the techniques employed by these programmers' high school english teachers, who seem to have successfully added an eleventh commandment to the Laws of Moses: "Thou shalt not employ the passive voice."

The fact of the matter is that the passive voice is a perfectly acceptable basis for sentence construction. Good english teachers warn against its *overuse*, but none would proscribe it. In fact, the passive voice can help to leaven what can otherwise become a tedious series of simple declarative sentences. You should learn to use it — judiciously.

That said, your thesis supervisor's stylistic requirements should *always* be given primacy—and many will insist that you refrain from the use of passive voice.

While arguments about grammar can be an endless source of diversion (or irritation!), I will simply close this section on the passive voice with a direct quotation from the entry in *Garner's Modern English Usage* (2009):

> **Passive Voice.**
> . . . [S]ometimes, you'll be justified in using the passive voice. There's no absolute prohibition against it—and anyone who tries carrying out such a prohibition would spoil a piece of writing. Among the times when you'll want the passive in a given sentence are these:
> - When the actor is unimportant.
> - When the actor is unknown.
> - When you want to hide the actor's identity.
> - When you need to put the punch word at the end of the sentence.
> - When the focus of the passage is on the thing being acted upon.
> - When the passive simply sounds better.
>
> Still, professional editors find that these six situations account for only about 15% to 20% of the contexts in which the passive appears.
>
> That means *you ought to have a presumption against the passive* [emphasis added], unless it falls into one of the categories just listed. (Garner, 2009, p. 613)

False Agency

Many students, in search of simple rules for writing, will simply eschew the passive voice instead of learning how to make effective use of it. Unfortunately, this conservative approach can give rise to a particularly insidious mistake that can cause great difficulties for a technical writer. Students writing in the third person will have to exercise extreme diligence to avoid

my frustration with writers who meekly acquiesce to Microsoft Word's insistence that these four letters require the addition of the French *accent aigu*, turning the standard's acronym into CAFÉ.

this error. And, while many writing instructors no longer proscribe the use of the first person in technical writing, the concomitant increase in conversational english in technical writing (generally a *good* thing) means that most students run the risk of making this mistake.

The error is what I call "false agency" — the (figurative) attribution of the ability to act to inanimate objects or to concepts.

> Aluminum recycling is an important area of modern research because of the substantial energy savings achieved by producing Al products from secondary materials; the energy needed to re-melt aluminum is 5% of that required for production from virgin ore [*citation omitted*]. Although Al is one of the more widely recycled non-ferrous metals, the proportion of Al that originates from secondary sources still has room for improvement. Globally in 2003, 13.1 million tons of Al were produced from recycled scrap while 27.4 million tons of Al were produced from primary material [*citation omitted*]. There are several challenges to increasing the proportion of Al produced from secondary sources. One of the explanations for the insufficient prevalence of secondary Al use in production recycling as a method for Al production results from insufficient automation and optimization of the recycling process [*citation omitted*]. An additional barrier to increasing the proportion of Al produced from secondary sources is the imperfect uncertainty in knowledge of the composition of the scrap, primary, and final materials. Compositional uncertainty is undesirable for Al recycling because it restricts the achievable yield of the process by necessitating inaccurate compositional estimations that lead to material loss [*citation omitted*].

Exhibit 10.1: An example of "false agency" in technical writing

To illustrate, consider the paragraph presented in Exhibit 10.1.[5] On a first reading, this paragraph seems a little stilted, with some odd language constructs (e.g., "One of the explanations for the insufficient prevalence of secondary Al use. . . ."). For someone in the field, the paragraph makes sense, but it requires a lot of work to figure out what the author is trying to suggest. And, for someone from outside the field, it is likely that even a persistent reader would be more than a little lost by the end of the paragraph (which happens to have been the opening paragraph of a research summary).

[5] Exhibit 10.1 is a concise example of false agency, because that's essentially all that anyone could really criticize about the paragraph. It is perfectly sensible English, and it is essentially grammatically correct. However, the reliance on false agency steers the argument into some rhetorical dead-ends almost immediately. Thanks to Tracey Brommer for permitting me to use this paragraph from an early draft of her MSL research proposal.

Deconstructing The Problem

Careful readers will find that a critical consideration of the final sentence of the paragraph raises some troubling conceptual questions: "Compositional uncertainty is undesirable for Al recycling because it restricts the achievable yield of the process by necessitating inaccurate compositional estimations that lead to material loss." The main clause is clear: "compositional uncertainty is undesirable. . . .[6]" But what do you learn from the defense given in the subordinate clause: "because [compositional uncertainty] restricts the achievable yield of the process by necessitating inaccurate compositional estimations that lead to material loss." Can compositional uncertainty really "restrict" anything?

Figurative Expression

Formally, one might refer to this framing of the consequences of uncertainty as "figurative." Figurative statements like this one are common, particularly in colloquial speech. "The rain kept me in the house all weekend" is perfectly understandable, but it is not literally true. Rather, a more truthful statement might be something like "I decided to stay in the house all weekend because I didn't want to deal with the rainy conditions."

Note the difference between the two expressions. In one, "rain" is given agency — the writer is stating that the the rain is acting to achieve an end, which is wholly inconsistent with the fact that the rain cannot "intend" anything. The writer is assuming that the reader will figure out the sentence's true meaning by drawing upon shared experiences or common understandings.[7]

Figurative Writing Is A Treacherous Shortcut

This form of expression can lighten a dry technical presentation; but it is dangerous when broadly used in technical writing. "False agency" and its kin make the writing accessible only to those who share the writer's knowledge and experience — as with the simpler "rain" example, without that common experience, the writing is confusing, if not meaningless.

Worse, reliance upon figurative expressions promotes a sloppy presentation of ideas. Eventually, the writer figures out that some of the elements

[6] Although the clause *does* maintain a certain air of mystery by never indicating *whose* desires are being represented here.

[7] For example, even the second form of the sentence takes on additional meaning(s) if it were attributed to, say, L. Frank Baum's Wicked Witch of the West or, alternatively, Isaac Cline from Erik Larson's *Isaac's Storm*.

This kind of deep meaning associated with otherwise simple expressions can be very powerful — consider, for example, Charles Foster Kane's dying word: "Rosebud." Orson Wells requires the entire film, *Citizen Kane*, to develop the meaning of this objectively meaningless statement. Powerful art, but entirely out of place in thesis writing.

> Aluminum recycling is an important area of modern research because producing aluminum (Al) from secondary materials requires only 5% of the energy required to produce aluminum from virgin ores [*citation omitted*]. Although Al is one of the more widely recycled non-ferrous metals, less than one-third of the aluminum produced each year derives from secondary material. (In 2003, 13.1 million tons of Al were produced from recycled scrap while 27.4 million tons of Al were produced from primary material [*citation omitted*]) Aluminum producers, however, cannot increase their use of secondary material without first resolving several important technical and industrial challenges. Observers have suggested that Al production facilities are inadequately automated and that the processes used to recycle aluminum are suboptimal. [*citation omitted*]. An important obstacle to improving the recycling process is the fact that the plant operator cannot know the exact composition of not only the scrap and primary materials that go into the melt furnace, but also the exact composition of the resulting product. Because these compositions can only be imperfectly known, remelters have designed conservative assumptions about composition into their processes. As a result, producers have "designed in" a suboptimal preference for primary materials over secondary ones, as well as an inability to adequately anticipate the risk of producing "out of specification" product (and the resulting material loss) [*citation omitted*].

Exhibit 10.2: One possible rewrite of the "false agency" paragraph

left implicit must be made explicit in order to pursue the argument. At that point, the writer (particularly one under time pressure) typically jams in an explanation. Morever, the writer will find that this sort of *ex post* repair must be repeatedly applied, eventually muddling the flow of the argument beyond all hope of repair.

Why "False Agency?"

If we return to the example paragraph about aluminum recycling (Exhibit 10.1), note that the actual agent is never mentioned. Things happen to aluminum, recycling of aluminum is widespread but somehow restricted, and compositional uncertainty is implicated — but there are no people involved! If there is a problem, who's causing it? Who's affected by it? Whose actions should be guided to remedy this problem and in what way? If these actors are left implicit, the author cannot actually state a thesis question. By making uncertainty a "restricter" of recycling, the only apparent options are either to eliminate the uncertainty or to "take away" its

ability to restrict — both nonsensical avenues of inquiry.

This is the danger of relying upon "false agency:" while it can simplify the presentation of your argument at the outset, it's a short cut that will come back to haunt you. Better to avoid it altogether.[8]

A possible rewrite of Exhibit 10.1 that formally eschews "false agency" is presented in Exhibit 10.2. With this rewrite, I have made it clear that the problem derives from a faulty process design, and that the inquiry will be an exploration of remedies.[9] In the earlier version of the paragraph, these elements are implicit; and, until they are made explicit, it is not possible to establish a realistic thesis question. From an artistic perspective, this second paragraph is a little less florid and possibly a little less exciting to read — but there's no possibility of the reader not understanding where the author is heading.

"Patchwriting"

Students should be aware that the writing strategy known as "patchwriting" can get you into serious difficulty. Howard (1995) describes "patchwriting" as a paper-writing strategy composed of the following elements: (*a*) the student "copies and pastes" various portions of multiple texts into a the skeleton of a manuscript, (*b*) the student then paraphrases these excerpts, and (*c*) the student weaves these paraphrased materials together to form a final manuscript for submission. Apparently, this strategy has been adopted by some writing programs, and Howard (controversially) suggests that that this method can help students who are struggling in the early stages of their writing process.

Students should recognize the substantial risks of the use of this approach for *any* writing project at MIT, and should be particularly leery of using this method when writing a thesis. There are many reasons for concern:

1. A document that is littered with direct quotations (particularly those without attribution) cannot be submitted as a draft for review by your thesis supervisor. Your use of direct quotations, instead of your

[8] **Beware:** The temptation to use figurative language is greatest when writing the introductory and background materials of your thesis. Figurative language can make it seem *soooo* easy to frame your problem — until you discover that the only readers who can figure out what your thesis accomplishes are you and (possibly) your advisor. Resist!!

If your desire to express yourself means that you simply *must* use figurative language, save it for your discussion and conclusion chapter(s), when you can reasonably hope that your reader will understand both your metaphor . . . *and* its limitations. **But remember:** few theses are read from beginning to end.

[9] Note that this choice is entirely my own construction. The paragraph, as written, admits to several possible ways to "get out of" this trap.

own words, will make it impossible for your supervisor to evaluate your own understanding of the subject matter.

2. There are real risks of failing to undertake the intended rewriting of the unattributed text, particularly as time pressures increase. If a document is submitted that contains such passages, a reader will be unable to avoid concluding that the author intended to plagiarize.

3. You will find that the practice of "patchwriting" is controversial. Many academics would not distinguish it from plagiarism. The MIT Academic Integrity website, while implicitly accepting that "patchwriting" takes place, tries to show students what is acceptable and unacceptable,[10] but you should recognize that distinguishing between the two is frequently a matter of opinion — and, as you will learn (or already have learned), the last thing you will want is to see that distinction being made during an adjudicative process before the MIT Committee on Discipline.

4. Finally (and probably most damning when it comes to thesis composition), "patchwriting" is essentially an acknowledgement that the paper or thesis writer does not understand the copied material. If the writer did understand the material, there would be no need to copy and paraphrase — the writer would be able to express the thought using his or her own words *with appropriate attribution*.

In the face of these concerns, I would *strongly* urge all TPP students to make a habit of using quotation marks *and* appropriate citations *whenever* inserting verbatim text into a draft document. If you must "patchwrite," recognize that it is far easier to remove these marks as a part of the paraphrasing process than it is to try to defend yourself when you find that you have overlooked (and, thus, failed to paraphrase) an unattributed excerpt during your final revision of your document.

[10] http://web.mit.edu/academicintegrity/plagiarism/paraphrasing.html

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Chapter Eleven

Some Other Useful Resources

There are other topics relevant to the preparation and presentation of your thesis work. Unfortunately, time constraints limit the ability to cover all of these, although this document will continue to be revised and updated as time and availability permit. In the absence of a section of this manual devoted to these topics, the following sections present lists of resources that may be of use to thesis students in need of specific guidance or help.

MIT Writing and Communication Center

While your thesis supervisors will certainly be intimately involved in your editing (if not your writing!) process, many students find that **MIT's Writing and Communication Center** (WCC) can be a very useful and helpful resource.

The WCC offers a variety of programs to members of the MIT Community (students, staff, and faculty) for almost any sort of writing project, and they have lots of experience working with students on their theses. Their services include individual consultations, workshops, and group activities designed to help you get over many of the writing hurdles that you may face.

See their webpage at https://cmsw.mit.edu/writing-and-communication-center/ for specifics.

Presentation Resources

While many MIT subjects are partly directed toward developing your skills in making presentations, many research groups will also require you to give talks, either internal to MIT or to conferences, etc. The texts listed below have been found to be of use. All three speak to the basics of what

makes a good talk, as well as describing, from a variety of viewpoints, how best to make use of presentation software tools.

- Stephen M. Kosslyn (2007). *Clear and to the Point: 8 Psychological Principles for Compelling PowerPoint Presentations*. New York, NY: Oxford University Press. ISBN: 978-0-19-532069-5
- Cliff Atkinson (2005). *Beyond Bullet Points: Using Microsoft PowerPoint to Create Presentations that Inform, Motivate, and Inspire*. Redmond, WA: Microsoft Press. ISBN: 0-7356-2052-0
- Nancy Duarte (2008). *slide:ology: The Art and Science of Creating Great Presentations*. Sebastopol, CA: O'Reilly Media, Inc. ISBN: 978-0-596-52234-6

Writing Guides and Grammar References

- Bryan A. Garner (2016). *Garner's Modern English Usage*. 4th ed. Oxford, UK: Oxford University Press. ISBN: 978-0-19-538275-1
- Diana Hacker and Nancy Sommers (2021). *A Pocket Style Manual*. 9th. Boston, MA: Bedford/St. Martin's Press. ISBN: 978-1319169541
- James P. Davis (2002). *The Rowman & Littlefield Guide to Writing With Sources*. Lanham, MD: Rowman & Littlefield Publishers, Inc. ISBN: 0-7425-1842-6
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Overleaf

In the summer of 2018, the MIT Libraries announced that MIT had arranged a contract for Overleaf open to all MIT students, staff, and faculty. As described in the MIT Libraries News & Events of Sept. 17, 2018 (Kohler, 2018):

> Overleaf is an online LaTeX and Rich Text collaborative writing and publishing tool that makes the whole process of writing, editing and publishing scientific documents much quicker and easier.

With Overleaf Pro+, you can:

- collaborate and share papers with others
- write in LaTeX or rich text
- find LaTeX errors and get support
- use pre-existing templates
- directly submit to some publishers

Of particular note are the templates that are readily accessible through Overleaf. In particular, a number of journal templates are posted there for use.

You can find with the MIT Libraries' Overleaf Libguide at (`https://libguides.mit.edu/cite-write/overleaf`).

Note that, while the MIT Thesis template is not there, it can be found at `http://web.mit.edu/thesis/tex/`.

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Chapter Twelve

Assignments for Thesis Students

Assignment: Thesis Formulation

Write a two page description and justification of the formulation of your thesis in five parts:

- Its central question or issue,
- The one or two key methods you will use to test or elaborate this hypothesis,
- The evidence or data available to support your answer,
- The feasibility of your approach within the time and capacities at your disposal, and
- The logic by which you will establish the point of your thesis.

Assignment: Abstract

First draft a preliminary abstract of your thesis in 300 words or less. It should cover:

- The point of your thesis,
- What you have demonstrated,
- How you did this,
- How you disproved alternative theories, and
- Recommendations.

Now, pull out the lead sentences of each paragraph in your abstract. If they do not summarize the abstract, then it needs to be rewritten.

Assignment: Time Budgeting

First, prepare a preliminary budget of your time in three steps:

- List the resources (data, facilities, professional skills) you will need for the thesis.
- Identify what you will have to accomplish to acquire these resources; indicate how much time and money are likely to be necessary to accomplish these tasks.
- Draw up preliminary schedule of how all these pieces could fit together realistically. Normally this will suggest some accommodations you may have to make.

Second, use a computer program to develop a preliminary:

- Schedule of the tasks involved in your thesis; and
- Bar chart of the level of effort you anticipate by week to complete the thesis.

Assignment: Literature

First, draw up a bibliography of the most significant material in your area. This should be in standard form: Last name of author, first name, (year), title of piece, publisher or journal, place of publication if book, otherwise volume number pages.

Then write a two-page report indicating why and how these references represent both the major schools of thought in your area, and the most significant contributors on your topic.

Assignment: Data Collection

Prepare a two-page report indicating and justifying:

- The evidence you intend to collect to support your thesis;
- Where your data may be found and how you plan to collect them;
- The amount of your time, the cost, and the delays required to obtain the data;
- How you will insure the reliability, validity, representativeness and significance of the data; and
- What you will do to maximize the efficiency with which you collect the data.

Assignment: Construction of Argument

Step by step, describe:

- The point you are trying to make. Use 1 or 2 sentences at most. Describing your point so briefly is, in fact, much more difficult than using fifteen or thirty sentences to talk generally about the subject. This is part of the point of the exercise, to get you to think hard about what you are really trying to say.
- What there is to demonstrate: You need to specify the distance between the point your thesis is trying to make and what is currently accepted by your audience. For example, if you are writing about privatization to economists you would not have to demonstrate microeconomics. If however, your audience consists of members of a public interest group, you might need to demonstrate why economics is relevant to their priorities.
- The logic you will use to show that your thesis is plausible, that is, consistent with findings of your research (or with other evidence).
- The alternative explanations for this evidence, for example, as generated by alternative political or professional perspectives.
- Why alternative explanations of your findings will be less satisfactory than yours.

Generally speaking, the parts of your thesis that do not relate to these 5 issues are extraneous on the principle that "Less is more," that is that less clutter, the clearer the message, the extraneous parts should be dropped from your thesis.

Appendix A

Rules of the Road for Research Assistants

This chapter contains the text of a document prepared by Joseph M. Sussman and Steven Connors in August of 2002 for MIT graduate students. Joe and Steve consented to its inclusion in this thesis manual, and students are encouraged to review it regularly.

Many graduate students at MIT have research assistantships which cover the cost of their tuition, and (we would expect) all or most of their living expenses. For many the educational value of their research is on par with that of their classes, developing and testing new ideas in greater depth than can be attained via coursework. Some are supported for nine months (September – May) and others for 12 months. Even so, it is important to remember that a research assistantship is a job; you are technically an employee of the Institute, with responsibilities different from students who are paying their tuition and living expenses by other means. A research assistantship is a special job: the idea is that your work on your research project links and reinforces your academic experiences and, in many cases, leads to a thesis. Nonetheless, it is a *job*.

The terms of employment vary from department to department and program to program. Most departments have a per semester units limit for research assistants, to ensure they have enough time to concentrate on their research assistantship duties. Different departments have different expected hours of work for a full-time research assistant. Typically this is in the range of 25–30 hours a week, encompassing a range of research tasks — background research, data collection, analysis, writing and coordination with others in your project or research area. This number of hours is intended to reflect an *average* workload for the research assistant. The faculty and research staff recognize that academic loads ebb and flow, and there may be weeks in which it is difficult for an RA to put in the expected

number of hours; on the other hand, there will probably be weeks in which the RA will put in many more than the expected number of hours such as early in the semester and during breaks in classes. However, in the long run, it should average to the expected number.

As an RA, you are a professional. We know of few faculty or staff supervisors that actually keep track of the number of hours you work, or whether you are actually at your desk during business hours and when not in class. Most supervisors are output-oriented. If your work is of appropriate quality and quantity, your supervisor will be happy, even if you are not at your desk from 9 to 5, and will be unhappy if your work is *not* of appropriate quantity and quality, even if you are at your desk "all the time."

So again, the job is a special one. Your relationship with your research supervisor should also be a special one. You should be professionally committed to doing the work you are being paid to do, and to the goals of the research project. The supervisor should be professionally committed to assuring a good research experience for you and, we hope, one that relates to your professional goals.

One perennial misunderstanding surrounding research assistantships is the relationship between academic holidays when there are no classes, and Institute holidays, when MIT is officially closed. Many students take for granted that academic holidays are vacation periods. *They are not.* The time between the end of the fall semester and New Year's is not an Institute holiday, except for Christmas and New Year's Day, and other days MIT may grant to give long weekends in that period. The same is true of Spring Break and the time from the end of the Spring semester to the end of May. This means officially you are supposed to be here and working on your research. Many RAs mistakenly think these periods are time off. *They are not.*

Now, having said that, many — not all — research supervisors will allow students to take some time off during these periods. Often it is with the proviso that the student take some work home with him/her to perform during that period. The faculty supervisor may make a judgment about whether or not the student should be permitted to not work during these periods, or work away from MIT, based on the faculty supervisor's views of the productivity of that student. A faculty supervisor may give one student permission to do so and not give another student the same permission. If you want that period of time off, or any other period of time off, *it is imperative that you ask your faculty supervisor whether that is permissible and not simply inform your faculty supervisor that is what you are going to do, or even just disappear without a word.*

By Institute rules, students appointed as research assistants for nine months get no vacation. Again, individual faculty supervisors may relax this rule at their discretion. A 12-month research assistant officially gets

two weeks of paid vacation. The choosing of those weeks should be done in discussion between the RA and the research supervisor.

I suspect this may strike some research assistants as overly hard-nosed. Our bringing it to your attention at this time is based on years of experience with relationships between RAs and research supervisors. Getting the rules down on paper in advance turns out to be the least painful way of handling misunderstandings on the terms of an appointment. In the lion's share of cases, very few of the above rules come into play. You do good work; your research supervisor is happy about it, both qualitatively and quantitatively; you get paid to do a thesis and to have a strong intellectual experience, while having your tuition paid and earning a stipend such that you do not go hungry or homeless. However, it is important to make clear before the fact what the obligations are in those few cases where these rules do come into play.

Joseph M. Sussman
Stephen Connors

August 20, 2002

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