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Statistical Consulting

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The ability of a consulting statistician to communicate effectively is very important. No surprise there, of course. Effective communication is certainly a desirable skill worth developing wherever there exists the need for interaction between two parties. During a statistician’s training, however, considerable emphasis is often placed on developing the necessary technical skills, leaving communication as something that can be “picked up later.” For the consulting statistician, “later” is no longer an option: good communication skills are required to be an effective consultant.

In this chapter, we specifically focus on the role of communication and explore some of the common elements and skills that are involved in effective communication. These are discussed in detail with a complete description of our approach and “how-to” guidelines are provided. Of course, developing good communication skills requires time and effort and our guidelines are not intended to be a substitute for this.

We begin by considering the following situation. When a statistician is involved in a project, a process takes place involving the transfer of information. Whether this is done with a group of collaborators or an individual client, there are certain common elements involved in the communication process:

1. Verbal interaction with the client(s) which continues until substantial progress has been made on a project.
2. Preparation of technical summaries, report writing, and presentation of results.
Certain skills will be required to perform these tasks effectively and in the next two sections we consider what is involved in interacting verbally with the client. Since the focus in this chapter is on communication, we proceed directly to the report writing stage of the project. While this presumes the analysis was able to be performed using the appropriate statistical methods, details concerning specific statistical techniques are covered in the next chapter and are not needed for our discussion on report writing.

We also discuss the role of oral presentations and provide details on how to make these presentations effective. The importance of quality graphics for presentation purposes is addressed in Section 2.6. A short introduction on the use of the PowerPoint software for enhancing presentations is given at the end of this section.

Before continuing, we must emphasize that any guidelines we provide for effective communication will not fit every consulting situation. However, it is hoped that the reader will benefit by having the opportunity to follow our approach in detail, and adapt it to specific situations as needed.

2.1 Verbal Interaction

There is a variety of situations where the statistician must interact directly with a client or group of collaborators. The main purpose of this interaction is to exchange information concerning a project of interest and to do this effectively the statistician needs to develop communication skills in the following areas.

1. Initiating the interaction process.
2. Understanding and defining the problem.
3. Evaluating the technical knowledge of the client/collaborator.
4. Assessing the overall issues and objectives of the project.
5. Identifying the statistician’s specific contributions to the project.

For the purposes of this discussion we refer to the client(s) or collaborators as simply, the “client.” While this word has certain overtones associated with it, the communication skills we need to develop are the same whether we are dealing with an individual client, or a group of collaborators. That is, these skills are not tied to a specific type of consulting environment where a certain nomenclature may be preferred.

Initiating the Interaction

So where do we start? How do we initiate the interaction? Deer (2000) and Bohn and Zahn (1968) both deal with this particular issue in detail and place considerable emphasis on the importance of creating positive first impressions. The physical setting of the meeting room and our initial nonverbal behavior towards the client will create their first impression of us — and we haven’t even said “Hello” yet. We consider some of these nonverbal cues in the example presented in Chapter 4. Common courtesy and respect obviously go a long way towards creating a positive environment for our consultation meetings. Some simple things we can do to help make clients feel comfortable when we greet them are:

1. Stop what we are doing immediately and get up to greet the client. We may need to take the client’s coat or indicate where they can put their briefcase.
2. Make eye contact and smile. This conveys the message that we are pleased to see the client and gives us an opportunity to assess the general demeanor of the client. If they appear rushed, give the client a little time to relax. Talk about the weather or other peripheral matters before asking about their project.

Once we are over the preliminary introductions, the client may want to show us some data, or mention a statistical procedure they want to use. However, it is necessary to start from the beginning. That is, we need to start with the context of the problem because without context, data have little meaning.

- How much do we need to know?
- Ask lots of questions.
- Always be prepared to take notes.

**How much do we need to know?** What we are really asking is how much information we need from the client in order to resolve the statistical aspects of the problem. Of course, the problem has yet to be well defined so some strategies are needed to elicit the appropriate information. The obvious approach is:

**Ask lots of questions:** At this early stage of the consultation it is often useful to have the client begin the session by describing the project in their own words. This gives us the opportunity to learn about the client’s field and make appropriate interruptions whenever unfamiliar
or specialist terminology is introduced. Never heard of the "EQRT" scale? Then ask! We are not expected to be an expert in every field of scientific inquiry. Now read the last sentence again. Why? Because neither do we need to become an expert in the client's field.

When we do ask a question, we must also listen (carefully) to what the client says. Remember that clients come to us for statistical advice. They cannot be expected to know that certain terminology has quite specific meanings in statistics. Saying a factor was "significant" implies something quite different to us than if they had said it was important. The reverse could apply just as easily, of course. The client could have said "important" when, in fact, they meant significant (based on a previous study, for example). In our experience, clients often tend to do two things:

1. Use statistical terminology inappropriately. We should always double check what the client means.

2. Fail to mention important variables such as design factors that were employed in the experiment. That is, we also need to listen for what is not said.

Always be prepared to take notes: Naturally, we were ready to take notes during this question-and-answer session. ... Do not assume we will be able to remember all the details about the client's project later. Taking notes during the consultation session is an essential part of the documentation process (Section 2.3) and we emphasize the importance of adopting this practice.

Defining the Problem

Our initial task is to try to understand the context of a project from the client's perspective. This means we need to learn something about the client's field and its associated terminology before trying to define the problem. As we become more familiar with the "context" of the problem and begin to communicate with the client using a common basic terminology, the purpose of our questions can then be directed towards the following aspects of the project. This information will be helpful in defining the problem and identifying the statistical issues involved.

- Background of the project
- Status of the project
- Aims of the project
- What the client expects

Background  Projects are often based on previous studies in which case there may be an established or accepted method of analysis. If so, obtaining a relevant reference from the client can help us ascertain whether the established method of analysis is reasonable and applicable to the client's problem.

Status  What is the status of the project? If the study is in the pre-experiment or planning stage, our contribution can be important in ensuring the planned experiment will produce reliable data for the subsequent analysis. If the data have already been collected, we will need to direct our questions towards the collection process. How reliable are the data? Is the client aware of any outliers in the data? Was the experiment performed in accordance with the usual principles of statistical experimentation: control, randomization, and replication? Is there enough evidence (sample size and structure in the data1) to support the objectives of the project?

Aims  What are the aims and hypotheses associated with the study? Are the client's objectives commensurate with the results that can be obtained from a statistical analysis? In some cases, certain hypotheses may need to be reformulated in order for the statistical analysis to provide valid conclusions. We should also make sure the client understands the distinction between causality and conclusions based on a statistical analysis.

Expectations  What does the client expect from us? We are not magicians, nor are we directing the project. Our responsibility should always be to the statistical aspects of the problem; it is the client's responsibility to articulate the importance and motivation for the project.

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1In one project, we were ready to start the analysis of a rather large dataset (100 MB) only to find out that a key variable had not been recorded in the original study. Hence the objectives of our project could not be met.
Technical Knowledge of the Client

Defining the statistical aspects of a client’s problem for ourselves is the easy part. Now we need to explain them to the client. At the same time, as we are defining the problem, it is useful (and sometimes revealing) to ascertain the client’s knowledge and understanding of the statistical aspects of the project. For example, a client may ask, “How large a sample do I need?” How should we respond? In terms of the power or accuracy of statistical tests, or with a more familiar notion like margin of error? This clearly depends on the client’s technical knowledge. In our experience, margin of error often provides a useful starting point and avoids possible misinterpretation of terms such as accuracy or precision.

- How well does the client understand the project?
- How much statistical knowledge does the client possess?

As we indicated above, there may be a basic or established statistical methodology that is well accepted in the client’s field. However, knowledge of a statistical procedure does not necessarily mean the client fully understands the concepts underlying the statistical procedure. Thus, part of our role can be an educational one. We consider some issues that may need to be addressed in this respect.

Educating the Client The client did not come to us for a statistics lecture! Our explanations should be given in the context of the client’s project; provide the client with an interpretation of the outcome and purpose of a statistical procedure, not the mathematical details. For example, a $P$-value can be explained in terms of “risk” rather than a probability based on some type of distribution. Be patient, but avoid getting stuck on details that are not essential — How much do we need to know? also applies to the client.

Level of Sophistication The statistical methods employed for analysis need to be appropriate for the problem and this may require introducing the client to more sophisticated approaches. However, we should not try to make the statistical analysis more complicated than is really necessary. The client needs to be able to interpret the results of the analysis irrespective of the level of statistical sophistication.

Formalizing the Problem A more complicated issue is the potential need to formalize the ideas of the client. They may think about their work in a more intuitive way which needs to be carefully formalized before the statistical analysis of the problem can be performed. The time spent in formalizing the problem is well spent because it will help the client understand the research from a statistical perspective. In some cases, this may even lead to a better formulation of the research objectives.

Example 2.1 There will be an interaction between PST and PREF by GROUP.

In Section 9.1 (Improving Teaching), the hypothesis stated above was the client’s best approximation to the “formal” hypothesis statement of the problem. What the client really wanted to know was whether the factors PREF and GROUP had an effect on the response PST. That is, was there was an interaction effect due to these factors.

Overall Issues and Objectives

At this stage we should have established a sufficiently good communication channel with the client and can now go into details concerning the overall statistical issues involved in the project. The following items should be able to be discussed in a language that we both understand.

- Aims and hypotheses of the project.
- Current or prior methodology, if any.
- Intended use of postexperiment results.

Objectives In some studies, the objectives may only be exploratory in nature and the appropriate hypotheses have yet to be formulated. On the other hand, if there are specific objectives of interest, we need to ensure that the experimental design will provide statistically valid results. If the experiment has not yet been conducted then we need to address issues related to the design such as sample size, randomization, and control, as well as implementation issues. If the data have already been collected, we need to consider whether the objectives of the study will be met by the current data. Additional data may be required.

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2 When asked, “How accurate do you want your test results to be?” a client promptly informed one of the authors they wanted the results to be 100% accurate. We quickly returned to the matter of determining an appropriate sample size.
Methodology  To ensure that the statistical procedure is applied appropriately, specific issues will need to be addressed such as:

- What is the data type of each variable?
- Are there outliers or missing values present?
- Do certain constraints exist in the process?

This requires interacting closely with our client during a consultation session. (Avoid confusing the client: missing values generally tend to be, well... missing!) We present an example of this type of interaction in Section 3.5, where some regression-specific questions are posed. We should also compare the current or prior methodology that is being used in the project with established statistical procedures that may be more modern or more appropriate.

Postexperiment  It can be worthwhile to consider the intended use of the postexperiment results. For example, does the outcome of the study depend critically on obtaining significance for a particular hypothesis? What are the consequences of getting a nonsignificant result? Make sure the client understands that we cannot simply change the result of an analysis because it doesn’t support the client’s initial objective.

Specific Contributions

The final stage of our verbal interaction with the client involves identifying our specific contributions. This is important to ensure that both we and the client understand clearly our respective roles in the project. The following items should be addressed as necessary.

Data management  If we are responsible for performing the actual computations the client needs to provide us with the data in suitable format.

Data Analysis  Error checking: The client needs to be aware that the initial stage of our analysis will involve checking the data. The client will need to provide us with any corrections.

Statistical Analysis  Both we and the client have agreed on the method that will be used to analyze the data and the details of performing the computations.

Report writing  Whether there is an expectation of presentation quality graphics and tables or any special requirements in the report that will be written.

Time frame  There needs to be a realistic time frame to allow us to perform the analysis and complete the written report for the project.

2.2 Other Aspects of Verbal Interaction

Persuasive Communication

In practice, the different components of verbal interaction that we have just discussed may be performed simultaneously. The art of persuasive communication requires the creative combination of these components to make the interaction with our client more efficient. Handling a consultation session well relies on good organizational skills. We should be prepared to interrupt (politely) and redirect the client towards relevant issues as necessary. This will make our consultation sessions more productive and enable the analysis phase of the project to commence.

Initial Contact

Prior to our initial appointment with the client, we may have already established indirect communication and gained some information about the project. In this case, the focus and direction of the discussion during this initial meeting may be predetermined to some extent. However, it is important that all prior information be reiterated at the beginning of the consultation to ensure there is mutual agreement on the content of previous communications. Doing this also helps to develop the nature of the working relationship between ourselves and the client.

Decision Time

In certain cases we may need to refuse participation in the project due to various reasons. For example, we may have constraints which would prevent us from completing the project in the time frame required by the client. In legal cases, there may simply be a conflict of interest because of our work with a previous client. In these situations, the decision not to participate in the project would usually be able to be determined prior to the initial consultation session.

What if the need to make this decision arises during the consultation session? Informing a client of our decision not to participate in a project can be difficult, but needs to be done during the initial stages of the consultation process whenever possible. It is crucial that the client is not led to false expectations of our intent to participate in the project. More important the client has invested their time in discussing the project with us and now needs to look elsewhere. The key issue is:

Knowing when to walk away.

3Our decision to decline a consulting project certainly needs to be made before performing any actual analysis; we may be legally or contractually bound to complete the project analysis if it is started.
Of course, knowing when to walk away does not mean we just simply up-and-leave! Indeed, an important part of our decision will be informing the client about the problems in their project and providing advice or recommendations that are appropriate to overcoming the limitations of the study. We may even generate a “new” project; this time with the added bonus that we can participate in the design phase of the study. Some reasons why the best option may be to decline a consulting project are:

- The sample size is too small for any meaningful analysis or is simply too large for our current computing resources.
- The data is biased or poorly gathered and there is no opportunity for further planned data collection.
- The client may not really understand their project or their expectations of the analysis results are unrealistic.
- We may not understand the client’s project or have limited expertise in the type of statistical analysis required for the project.
- We have moral or ethical objections to the project. This includes statistical ethics such as a client who “requests” a particular method of analysis which is clearly inappropriate.

**Negative Outcomes**

“Oh, I’m sorry. Here. You can put your gum in this (the waste basket).”

Since the context of the statement is missing, two possible scenarios in which this statement could have arisen are: we were a bit slow in picking up the client’s nonverbal cues; after starting the consultation meeting, we noticed the client was chewing gum. In the first scenario, our statement was simply a response to a nonverbal request initiated by the client, prefaced by a genuine apology as a friendly gesture. In the second scenario, our statement clearly served a different purpose: we were attempting to address a “negative” situation that occurred during a consultation session.

The above scenario is somewhat trivial, of course, but it does provide a useful example for illustrating some of the issues that the statistical consultant may need to consider when attempting to deal with negative situations. These are summarized below.

**Perception**  What is the problem? Every client has mannerisms and idiosyncrasies that we may find “annoying,” but this hardly counts as a negative “situation.” Addressing unimportant problems will only make the situation worse. If a client chewing gum is not a big problem for you, let it slide.

**Consequences**  What are the consequences of addressing a problem?

- By exposing the situation, we may convey a very negative impression to the client. (The client may be offended by the way we made the request: “What’s with the insincere apology: ‘Oh, I’m sooo sorry.’ ”)
- We may end up spending valuable time on issues unrelated to the client’s project. (The client berates us for using the indirect approach. “You could’ve just asked me straight out.” The situation is now worse and we need to spend more time trying to make the client feel less slighted.)
- It could backfire on us. (The gum is something the client needs for medical reasons. We assumed it ordinary gum and now face the two problems above.)

**Timing**  When should we address the problem? It is usually better to address simple problems immediately, but in some cases it may be better to “sleep on it.” That is, defer addressing the issue until the end of the consultation session. Perhaps even try to think of a creative solution to employ at the beginning of the next session which might circumvent the problem.

**Win-Win**  What is the purpose of addressing a negative situation? The aim, of course, is to achieve a positive outcome. The consultant and client both benefit from understanding what the problem was and are able to move on to more important matters. Deer (2000) refers to this as a “Win-win outcome” and provides numerous examples of positive and negative situations that a statistical consultant may encounter.

**Continuation . . .**

Developing good communication skills is an evolving process and while experience will certainly help, it is important for a statistical consultant to continually reassess their performance. How might that difficult situation we got into last week, have been better resolved? Why did it take two meetings to clarify the objectives and work assignments for this project? Cultural differences may also have an impact on our interaction with a client. Clearly, we have not addressed every aspect of verbal interaction in our presentation above, nor have we considered all the different types of consulting situations that a consultant can expect to encounter.

Fortunately, there are many other resources available that can help us improve our communication skills! The text by Deer (2000) and accompanying video are certainly worth looking at. Some articles relevant to this section are: Tweedie (1998), Finney (1982), and Lurie (1958). Finally, business-oriented publications often provide useful advice that can be incorporated into the statistical consulting environment. See, for example, Hamilton and Parker (1993), and Yeatts and Hyten (1998).
2.3 How to Write Reports.

Our statistical analysis is now complete. The results supported most of the project’s hypotheses, and we have an hour free to whip out that “report” the client requested. Great! Sounds simple enough so let’s get started. What do we need? Some sort of introduction, the results, and our conclusions. The computer output? That can all go in an appendix at the end. Done! Not quite. In our contacts with leading researchers in industry, the most prevalent complaint we hear from these scientists is that our statistics graduates have great difficulty in writing reports. Indeed, there are cases where industry scientists involved in a project routinely reject the inclusion of a junior statistician who does not possess good written communication skills. While this may seem unfair, the “good job” we did on the analysis is of little value if nobody can understand our written report!

The objective of this section is to provide guidelines on writing reports. These guidelines do not guarantee “quality,” of course — unintelligible content will remain so even when it is well formatted. Furthermore, reports produced in the workplace often need to satisfy specific constraints which may differ from some of the guidelines we suggest here. However there are some general principles that can assist with the process of writing a report.

- Our work needs to be well documented.
- We are subject to a finite time frame.
- Reports need to be concise but understandable.

Documentation We cannot emphasize enough the importance of making sure that all our work is well documented and that our findings reach the appropriate people in writing. When we write a series of reports on a particular project we are establishing a paper trail that documents our contribution to the project. Examples of the type of documentation involved in a project are provided in Chapter 4.

Time frame There is usually a finite time limit for which the documentation and reports are expected to be available in a presentable format. In order to accomplish our objectives efficiently, we should try to set up and follow realistic time frames for the completion of our reports.

Readability Every report we write is directed to a specific group of readers. The report needs to be understandable and should be written at the appropriate level for that group. The report should also be written in a reasonably concise manner. Information that is well-known to the reader may not need to be included in the text, or only briefly stated as is necessary. The important points of the report, however, must be elaborated very carefully.

We do not pretend that our guidelines will teach the reader how to write in a general context, but they should provide some insight into the specifics involved in writing a report to our group, our superiors, or other readers of our work. In this spirit we introduce a very precise style of writing reports.

Project Outline

The project format that will be followed in this book has the structure shown below. In reality, we may need to make modifications to this structure but at least this provides the reader with the chance to learn a specific way of writing reports.

- Title page
- Introduction
- Results
- Conclusion
- References
- Appendices

Title Page

The title page is very important because what is written there reflects tremendously on the chances that our report will be read and understood. The information on the title page should give the reader a clear idea of the content and important points of our report. The structure of the title page is shown in the example in Figure 2.1. It contains:

- Project title
- Author(s)
- Date
- Executive summary

Project title The title, name(s), and date provide the citation information for the report. Try to choose an informative or “interesting”
title: Final Project Report tells the reader nothing! However, be careful when dealing with a subject where people's sensibilities may be offended. We comment further on this with regard to the PowerPoint title slide example shown in Figure 2.4.

Executive summary It must be very short and to the point. The executive summary contains a brief account of our conclusion. Do not describe the problem or discuss the type of methodology that was used; simply state the results and conclusion. For example,

"The IBM stock price was at a higher level in October than in November. In October the mean price was ..."

The example of Figure 2.1 illustrates that the executive summary is short and to the point. Remember that the executive summary tell the reader what happened. It is not an "Abstract" which tells the reader what will happen. Abstracts precede articles published in journals. Consulting reports are specifically directed to our client.

Introduction

The purpose of the Introduction is to describe the project (insofar as we were involved), and to give the necessary background information. Try to be brief but do not leave out relevant information. Here, the basic descriptive statistics, graphs and summaries of the data can be included. If we have several graphs or large tables put them in an Appendix and refer to them in the text.

Results

State the points or hypotheses and prove them or disprove them. Go point by point showing how we performed the corresponding hypothesis test and how the results are to be interpreted. If we used statistical software that generates a sizable output file, extract the pertinent information and place it in the Appendix in table format. Do not simply dump entire output files into the Appendix. This practice is unprofessional on our part and it is not the reader's job to "find" which particular part of the output we are referring to in the text.

We should point out that certain report formats do require that entire output files be included. For example, the FDA requires that reports from the pharmaceutical industry also contain the source code used to generate the output file.

The Stork Reality

by

Amis L. Eding
Corel A. Shun

January 1, 2000

Executive Summary

This report contains evidence of a strong correlation between the population of Oldenburg and the number of storks observed over a period of seven years. Clinical tests conducted during this same period however, account for 95% of all known births in Oldenburg. A causal effect is not suspected for the other 5%.

FIGURE 2.1. Title Page Example
Conclusion

The conclusion section should be an extended version of the executive summary. When writing the conclusion bear in mind that it should be in the form of a contextual interpretation of the results presented in the Results section. We should refrain from heavy reliance on excessive technical terminology. That is, the conclusions we make should be substantiated by the facts from the Results section and should explain what the results mean with respect to the goals and terminology of the project. In industry, for example, the language of real costs ( $$$ ) is extremely important in reports to senior management. Relating our conclusions to productivity and cost savings can provide a big boost to acceptance of the information.

References

The Reference section is the list of books, articles, software and other documents that were cited in the text. Do not include irrelevant references that are not specifically related to the project. Certain references such as legal documents or technical reports, would also be included in an Appendix if they have particular relevance to the project. If we do not have any references to cite, then omit the Reference section completely; we are not required to have it. The general rule for a citation is to write the author’s names (last name, then initial of first name) followed by the year of publication, title of the work, and then the general publication information as appropriate: journal, volume, pages, publisher, etc. The bibliography in this book provides examples of many standard citation formats.

Appendix

The Appendix should be used for computer output, computer code, graphs, tables, or any other reference documentation that need not appear in the text. Again, do not use the Appendix as a dumping ground; it needs to be presented in an organized and appropriate format for the reader. Try to adopt a suitable indexing system within the Appendix that can be used as a reference for any place in the output we quoted in the text of the report. This could involve: underlining and numbering the relevant places in the output and referring to those numbers in the text, or employing designations such as Table 2B and Figure 3.4. Highlight the text or numbers using a light color marker (translucent yellow is a preferred color) to make them easy to find. If the amount of documentation is extensive, the Appendix can be broken into several sections. For example, graphs could be kept in one section, tables in another, letters from a relevant law case in another, and so on. If several analyses were performed, it may be useful to keep the results in separate appendices. Preceding the appendices with their own table of contents (in addition to the one for the entire report) is helpful.

2.4 Basic Guidelines for Writing

The purpose of the previous section was to provide a structure for writing reports. Now we need to fill in the structure of our report with actual details. A word of caution — the time needed to “fill in” the details can be deceptive. A report is not complete until all the parts have been written. While this would seem to be stating the obvious, remember that our submitted report can only be assessed on the basis of what has been written. The reader is not responsible for guessing what we meant to write, mistakenly omitted, or intended to “fix later.” The style and quality of our writing also deserve attention and we consider some general guidelines that may be helpful in this regard. In reality, good writing takes effort and experience: guidelines are not a substitute for this learning process.

Of the numerous references on writing we mention Gopen and Swan (1990) which is posted on the the Journal of Computational and Graphical Statistics (JCGS) section of the ASA Website: www.amstat.org

Some Basics

Spelling Typographical errors are distracting. Our favorite spell-checker can be helpful, but it is not infallible. A dictionary can help us check the appropriate usage of a particular word.

Fluency Our sentences must make sense. Reading the sentence aloud can often help identify problems with syntax and construction.

Paragraphs All the sentences in a paragraph should be related to a main point. Digressions tend to confuse the focus of the reader and this can result in our point being misunderstood.

Revisions Whether we continuously revise as we write, or wait until a complete draft is finished before revising, no final report should be submitted without performing a careful check. A good strategy is to have somebody else read our draft.

Example 2.2 Outlier

Statistical terms often have a strict technical meaning which will not be recognized by a spell-checker. Two common examples are “estimator” and “outlier” which certain spell-checkers may try to replace with estimate and outlier. Unfortunately, the latter term has appeared so often that it would seem that we have a new term for “Outlier” in statistics!

Example 2.3 Their, there

No, this is not an expression of sympathy! The first form, their, is used only as an adjective to indicate possession by a person or a group. “It
was their idea.” We should note that their does not distinguish between a singular or plural identity: is this one person’s idea or a group’s idea? The writer needs to establish this. It follows that there should not be used to indicate possession. Incorrect usage of these two words will be very obvious to the reader.

**Style**

An important part of our preparation is knowing “who” will read our report. The client who initially brought us the project may well need to share our report with other people. Thus, our style of writing, should be commensurate with the overall level of statistical knowledge of the anticipated readership. In addition, the quality and style of our writing should be considered. It is not an impossible task to convey technical information across disciplines, it just requires more attention and care on our part as to what we write. The following example exaggerates a style of writing which we should **never** use!

Based on the Type III SS, for the LS fitted **regression** model MRL = I1b. (Appendix II, Part C), which included the “X variables” AGE88 AND HGT-1, HGT-1 is **not significant** [NB: P=0.2345]. This means HGT-1, **given AGE88**, does **NOT contribute** in the ‘PREDICTION’ of the **response**, INC (Y).

**Emphasis** Important words or phrases can be made to stand out by **changing fonts**, or using CAPITALS. However, if used too often (or inconsistently), the effectiveness is rapidly lost and our report becomes “tiring” to read. Similarly, excessive use of **acronyms** is unnecessary. The reader should not have to decode our report in order to read it!

**Clarity** The clarity of a sentence is more important than its length. Each sentence should be trying to convey a self-contained “packet” of information to the reader. Short sentences are fine, but always using short simple sentences will make our writing seem “choppy” and the reader feels like the flow of our narrative is being constantly interrupted. Similarly, long rambling sentences which keep adding divergent bits of information will lose the reader. They give up accumulating the information before the sentence is finished, make an interpretation at this point, then skip to the end.

**Paragraphs** A paragraph consists of a series of sentences which should all be related to a central theme. Although the structure of the paragraph will depend on the theme, there should be a natural flow of information between sentences. That is, we need to present the theme of the paragraph in an organized manner. In report writing, two types of paragraph structures are **Thesis** and **Linked** (see Example 2.4).

**Technical Details** Most reports will need to contain technical details concerning the statistical procedures we employed. If we are unsure of the readers’ level of knowledge, keep the technical details of the statistics to a minimum. Citing an appropriate reference to a statistical procedure would be more appropriate than writing an entire textbook on the procedure!

**Example 2.4 Paragraph styles**

**Thesis:** Say the thesis ⇒ Prove it ⇒ Say it again.

This structure is a good way to write the Executive Summary. It is also useful for describing the results obtained from a particular type of statistical procedure, or for stating our conclusions based on the regression analysis we performed. Try not to add too much related information in a single paragraph. Rather than overwhelm the reader all at once, break the original theme into cohesive subthemes.

**Linked:** Linking sentences:

\[
\text{[ Topic A ]} \Rightarrow \text{ [ New Info A ]} \\
\text{[ Topic B = New Info A ]} \Rightarrow \text{ [ New Info B ]} \cdots
\]

By “⇒” we mean that the words in each sentence connect an introductory “topic” with a “new” piece of information. This new information becomes the introductory topic in the following sentence which then connects to the next “new” piece of information, and so on. This type of structure can be useful for the initial paragraphs of the Introduction section of our report where we need to describe the details of the project: aims, variables, sample size, etc. Thus, this structure is useful whenever we need to describe a **sequence** of related conditions, or the **progressive** steps of an investigation.

For example, the diagnostics associated with a regression fit could be linked as: Scatter plot → residuals. Residual-versus-fitted plot → normality. Normality tests → significance results. Nonsignificance → conclusions.

**Example 2.5 The apostrophe**

The apostrophe ‘ is used to indicate possession — The client’s data — and for contractions — won’t, can’t, etc.

Although contractions can be avoided by using the expanded form (Don’t — Do not), this tends to make our writing cumbersome since the style appears unnecessarily formal. This formalism imposes a certain emphasis which can detract from the point we are trying to convey to the reader. ‘Don’t forget to plot the data’ reminds the reader to “plot the data” whereas, “Do not forget to plot the data” admonishes the reader for “forgetting.”
Example 2.6 However, thus, hence

Try to avoid writing the report in the style of a mathematical proof. Not every sentence needs to start with one of these qualifiers. Although we may be accustomed to their frequent use in technical expositions, this should not be necessary in the report. Eliminating the needless use of these qualifiers may take a conscious effort on our part, but simply stating a result is often sufficient.

English as a Second Language (ESL)

For writers whose native language is not English, performing the checks listed above may not be easy. Based on our experience, students in this situation can find the correct use of articles and punctuation to be particularly troublesome. If this situation applies to you, obtain a reference handbook on writing; preferably one that includes ESL advice. The handbook, A Writer’s Reference, by Diana Hacker (1998) includes specific ESL advice and would be a useful reference in general. Having a native speaker of English read your drafts would also be helpful, provided you treat this as a learning experience and not as a way to avoid the problem. Of course, you still bear sole responsibility for quality and content of the final report. Finally, the benefits of enrolling in a writing course, whether ESL or not, should not be overlooked.

2.5 How to Make Effective Presentations

The art of communicating with an audience is not just a natural gift as some may pretend. There are people who are gifted with verbal communication, but for the rest of us it is a matter of preparation. We may not be able to emulate the great orators, but anybody who prepares properly will be able to deliver an effective presentation.

The type of presentation we prepare will obviously depend on our audience. If we are just presenting the results of our analysis to one or two people (our client), then a complex multimedia show would be completely inappropriate in most situations. (The case where the client happens to be the CEO of a large corporation is clearly not “most” situations.) While some of issues we present below do apply to one-on-one presentations, the emphasis in this section is on formal presentations. That is, the situation where we need to provide our client with a well prepared presentation of the “product” (the data analysis) that they paid for. Small business consulting companies need to do formal presentations all the time, and we should expect to do the same with any large consulting project.

In order to deliver an effective presentation we first need to consider the various aspects that are involved in nonverbal language and voice quality.

- Nonverbal language.
- Voice and speech.
- Preparing for the presentation.

Nonverbal Language

Nonverbal language has an important role in a presentation. Our body language can be very expressive, both from a positive and negative perspective. Some things to try to avoid are to appear too nervous, to move around too much, or to face away from the audience and look only at the screen. Obviously our attire and physical appearance should match the circumstances in which the presentation takes place. Equally important, our manner should invoke enthusiasm for the subject matter. Nonverbal language conveys a lot about ourselves and the quality of our work.

Voice Quality

Voice and speech intonation can enhance the delivery of a presentation. We have to learn to project our voice into and above the audience without shouting. Practice can help us with this. If our voice is too soft then we need to practise speaking louder and higher up in the air. Intonation is also very important; there is nothing more frustrating than trying to listen to a speaker droning on in the same tone. By varying the intonation of our voice we can stress specific components of our presentation so as to add emphasis to the important points. The text by Dunckel and Parnham (1993) may be useful here.

Preparing for the Presentation

Once we have finished the analysis and gather all the information that has or will appear in the report, we should prepare for a possible presentation. The first step is to try to establish the length of the presentation and to prepare the structure accordingly. It is common for inexperienced presenters to overextend themselves by trying to say too much or having far too many slides. Try to be reasonably conservative in terms of the material and the timing. Saying “less” is often much more effective than trying to include everything.
2. Communication

- Structure and timing.
- Multimedia, PowerPoint, overheads.
- Slide preparation.
- Objectivity.
- Handouts.
- Practice the presentation.
- Be prepared for possible questions.
- Get advice from a colleague.
- Time the presentation!

Structure
The structure of the presentation can be similar to the report structure. Start with a summary of what we are going to cover and then follow with a general introduction to the problem under consideration. Then continue with a more detailed results description and finish with the conclusion. We do not have to include as much material as in the report and we also have a chance to be more creative. Sometimes it may be useful to make use of the introduction to motivate the audience if they are unfamiliar with certain aspects of our discourse.

Choice of Media
Another component to consider at this stage is the medium that we intend to use. This can vary from simple black and white transparencies to the most complex multimedia show. The preparation time is proportional to the complexity of the medium, but if it is done well a fancy multimedia presentation can be extremely effective. On the other hand the medium is not a substitute for content and it should not overshadow the substance of the presentation.

One way to enhance our presentation is to use color. A typical middle ground presentation requires the use of color and enough graphical sophistication that makes necessary the usage of a presentation software such as PowerPoint.

Slide Preparation
Next it is time to prepare our slides. This needs to be done carefully. It is important to emphasize the content and not so much the form. Do not abuse special effects and "junk-chart." The fact that those tools are available in the presentation software does not mean we have to use them all on every slide. Some other points to keep in mind when preparing the slides are:

1. Tables should be kept to a minimum. The use of charts and graphs is far more effective for conveying information.
2. Annotations should be kept to a minimum. These can be visually distracting.
3. Color choice is important. Never use yellow (it will be invisible to the audience) and avoid certain combinations like red on dark blue.
4. Lastly, make sure that we have the right number of slides; not too many, not too few.

If our presentation is very complex or requires careful comparisons of pieces of information (for example, tables or charts) we should consider preparing handouts as well. If we need to reinforce certain points then use slides and an additional projector.

Objectivity
Always remember that as a statistician and as a scientist, we are obliged to provide an objective and honest presentation of the information. Many of the tools that are available for presentation can be used to bias the evidence towards a certain conclusion which is not warranted. More important, we should not be afraid to say that we are unsure or uncertain about a result. Let the audience see the "problem." In our experience, we have often found the audience to be the best problem solvers!

Practice
Once the details of the slides have been completed we should practice the presentation in a realistic setting. Time the presentation! Presentations that end up going overtime lose audience interest rapidly. Be prepared to answer questions during the presentation. This time will need to be incorporated in the total time we plan to use for the presentation. Slide flexibility is a useful strategy here as we won't know how many, or what type of questions we may be asked until after the presentation. This just means that we should have certain slides that can be omitted entirely or discussed in varying degrees of detail depending on whether we need to "speed up" or "slow down" the presentation. This does take practice, but avoids the visual appearance of a "rushed" presentation:

- No questions are asked and we finish in half the time allotted to our presentation! The audience is left with the impression our presentation lacked content.
• Many questions are asked and we have to flip to the end of the presentation. Our timing is perceived to be poor and the audience is wondering what material they missed seeing.

Questions raised during the presentation are often short and quick, requiring simple clarification of a term, concept or entry on a graph or table. At the end of the presentation however, we should be prepared to answer more probing questions. We should make a list of questions that we can expect and prepare the answers beforehand. Our answers should be directed to the full audience (not just the person who asked the question), and need to be pitched at a level which everyone can understand. Finally, it is well worthwhile rehearsing the presentation in front of others who can help us correct obvious errors and polish the details of the presentation.

2.6 The Importance of Quality Graphics

| Aesthetics | Efficient use of the plot region. |
| Annotation | Labels, legends, title and subtitles. |
| Contrasts  | Grey scale, color, lines and symbols. |
| Comprehension | Conveying information graphically. |

Many statistical procedures rely on graphical diagnostics and data visualization techniques for analysis purposes. Scatter plots, histograms, and bar charts are examples of simple but very effective graphical displays that can be employed to communicate the results of our consulting efforts. In this section, we focus on some of the important principles of graphical design that are involved in creating Quality graphics for presentation purposes. These principles are indicated in the box above.

The first thing to note is that producing presentation quality graphics takes time and effort. Even with a good statistical software package such as S-PLUS, the “default” display will often need to be modified for presentation purposes. One advantage of S-PLUS is that it allows the user to exert precise control over the components which make up a graphical display.

The Plot Region

The term figure is used to describe a complete graphical display which is composed of a plot region surrounded by four margins (top, base, left and right) as depicted in the time series schematic plot of Figure 2.2. The margins are used for titles, axis labels, tick marks and labels, and other annotations. The right margin usually contains no text and could be minimized to increase the plot region area. Where practical, legends can also be placed strategically inside the plot region (see Figure 2.3) to avoid reducing the area available for the graphical display.

Graphical Design

The example in Figure 2.3 illustrates the use of histograms to display the results of a two-sample t-test based on a study to compare the effect of incorporating learning style preferences (Experimental Group) versus traditional teaching methods. We use this example to discuss the graphical design principles above.

Aesthetics  The purpose of a figure is to convey information visually. The aim of enhancing the aesthetic quality of a figure — making it look “good” — is to focus attention on the displayed graphic. This

4Bar graph and bar plot are synonymous terms for bar graph.

5Details of this study are presented in Chapter 4.
2.6 The Importance of Quality Graphics

Involves making efficient use of the plot region and margin spaces which often requires a trial-and-error approach. Some general points to keep in mind are:

1. The displayed graphic should span the vertical and horizontal dimensions of the plot region.

2. Sufficient space must be provided in the margins for explanatory text in larger font sizes. The default font size employed for axis labels is often too small, making it impossible for the audience to read in a presentation setting.

3. Reducing the width of the right margin space (see Figure 2.3) has a side-effect of making the graph appear off-center. Compromises are a necessary part of improving a graph.

4. The title and axes labels are necessary text. Additional text will have the effect of adding visual clutter to the display and should therefore be used sparingly.

5. Color or grey scales, line types, point symbols, font sizes, and legend placement need to be experimented with. Visual contrasts are very important in helping the viewer distinguish groupings and other effects.

6. It is not necessary to change every default setting provided by the software package. If the default setting is acceptable, don't change it!

**Annotation** The margins are used for titles, axis labels, tick marks and labels, and other annotations. In Figure 2.3, the title also served as the X-axis label.

1. Keep axes labels simple (but informative), and use "nice" tick marks. For quantitative scales, the unit of measurement should also be included in the axis label.

2. Legends add to the visual clutter so choose the legend information carefully. In Figure 2.3, the histograms provided a visual proxy for the group spreads and sample sizes so only the mean of each group was included.

3. Other annotations such as the text indicating the significant result in Figure 2.3 may be helpful or necessary. For example, the baseline used to display relative percentages needs to be indicated in order for the viewer to make a meaningful assessment.

**FIGURE 2.3.** An example of comparative analysis using Histograms.
Conversely, if we decide to use color to differentiate lines or points in the presentation **do not use yellow** — they may not be visible.

1. Color provides the viewer with a wider range of contrasts and can also add extra dimensionality to the graphical display. In Newton (1993) for example, color-encoding was employed as an aggregation technique for displaying very long time series. It also introduces more complexity in terms of interpretation and aesthetics. (We refer the interested reader to the extensive work by Carr (1998) on data visualization methods using color.)

2. The choice of colormap is important when translating color graphics to greyscale devices. Black-and-white photocopiers can often render a noninformative version of a color graph. Obtaining a reasonable greyscale for presentation graphics can be surprisingly difficult. In Figure 2.3, the top histogram “color” is still too dark.

3. The default size provided by many software packages for points in a scatter plot is usually inadequate for presentation purposes. These need to be replaced by larger symbols such as the opaque diamonds in Figure 2.2.

4. The number of contrasting lines that can be employed effectively in greyscale displays is quite limited. Simple dashed and dotted line types are better reserved for internal horizontal or vertical median lines; unbroken curved lines marked with different symbols are easier to differentiate than mixtures of dot-dash line types. The line width (thickness) is sometimes increased for the axes lines or for emphasis as in Figure 2.3, where the groups means are connected by a slightly thicker line.

**Comprehension** The most important component of graphical design is making sure the display conveys comprehensible information. For example, the time series schematic in Figure 2.2 is actually showing how the technique of “wrapping” a time series on itself is performed — the two points which connect across the right edge of the plot region are redrawn in the same position relative to the left edge of the plot region. This data visualization technique was employed by McDougall and Cook (1994a,b) in an interactive dynamic graphics environment. (Interactive graphics are discussed further in Chapter 3.) Although the concept of this real-time animation technique is straightforward, Figure 2.2 clearly required additional explanation in order for this transfer of information to be completed.

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6One of the authors had the dubious distinction of providing their doctoral advisor with a transparency in which three time series plots were overlaid. Only two showed up at the presentation.

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**Using PowerPoint for Presentations**

PowerPoint is an excellent tool for presentations and perhaps more importantly, provides “templates” which makes it easy to generate a good basic presentation. Of course, other presentation software can be used for this purpose and our choice of PowerPoint is mainly motivated by its ease-of-use at the default level and wide availability. PowerPoint will display a sequence of slides with the presenter advancing each slide in accordance with the pace of the presentation. We can also add special effects such as automatic timing, sound, and animation. Special effects can certainly w
hance and help add vitality to the presentation, but they can also be more of a nuisance factor and divert the attention from the important points. As in many situations, moderation usually wins out.

Preparing for our PowerPoint presentation follows the same steps as discussed in the previous section:

- Prepare the slides carefully — not too many, not too few.
- Avoid using too much "junk-chart" material.
- Provide handouts or use additional slides on an overhead projector if we need to reinforce certain points in the presentation.
- Above all, rehearse! Time the presentation under the type of conditions in which the presentation will take place.

The key difference is that this is an electronic presentation which means computer hardware, cables and software will be required. The most common setup is where our laptop computer is connected to an electronic display unit which sits on top of an overhead projector. Prior to the presentation, we need to do the following:

1. Find out what equipment we need to provide for the presentation.
2. Make sure the laptop is compatible with the electronic display unit and has the right cables for connecting.
3. Learn how to operate the display unit with the laptop. Certain control settings such as Video Mirroring may need to be turned on.
4. Know how to use the laptop! Spending several minutes trying to find PowerPoint or our presentation files would not be a good start.
5. Always, always, have a backup copy of the presentation. Computers do crash and can erase our carefully prepared PowerPoint slides.

The following instructions will enable us to produce a basic presentation. To enhance the presentation we can check out the many options available in PowerPoint and the Wizard tool. Examples of slides created by PowerPoint are shown in Figures 2.4 and 2.5. Before continuing, we again emphasize the following important point:

Presentation software is not a substitute for content.

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A cure for Cancer

Alexander F. Leming
March 20, 2001

FIGURE 2.4. Example of a Title Slide using PowerPoint

Click on PowerPoint This will take you into a menu where you may choose to run the Autocontent Wizard or to select a Template. We recommend that you select a simple template. In the slide examples of Figures 2.4 and 2.5, we have used the Blank Template. We added a light background color from the color menu obtained by selecting the Background item from the Format menu.

Title Slide PowerPoint will bring the title slide to the screen and you can now fill in the presentation title, our name and date. Figure 2.4 shows a simple example.

New Slide Next you click in the New Slide of the Common Tasks window. This opens a window showing the slide autotemplates. Choose the one that best suits the intended purpose of the slide (e.g., text only, text with graphics, etc). If you want a different layout you can always
change it later. You can now enter the text of the second slide, adding
graphics or pictures if applicable. Next you repeat the process until
you finish all our slides.

Pictures  You can insert a picture on a PowerPoint slide by using the
Picture + From file item on the Insert menu. Figure 2.5 shows
an example of this. PowerPoint will accept a variety of graphic formats
files including GIF, JPEG, EPS and PNG.

Statistical Graphics  To incorporate a picture from S-PLUS-PC save
it as a GIF file. In S-PLUS running under UNIX, use the PostScript
graphics driver with the option onefile=F, so it will save each picture
on a different file in the EPS format. In SAS you can select the export
item on the file menu and select the GIF format. Any of these picture
files formats can be read by PowerPoint.

Reviewing  To play the presentation select View Show from the Slide
Show menu. To go to the next slide press return.

Results

- Smokers 40 or younger
  are cured within one year
  of quitting.
- Women older than 40
  are cured within two
  years.
- Men older than 40 are
cured within three years.

FIGURE 2.5. Example of a Results Slide using PowerPoint

An alternative method to generate slides for presentations is to create
HTML files. An easy way to produce HTML file presentations is to use
the Netscape Composer which is a Web page editor that is easy to use and
comes with later versions of Netscape. Netscape is available free of charge
for most nonprofit organizations and many businesses have site licenses.
Netscape Composer works more or less like an editor. We can change font
type, face, size, and color and we can add pictures to the text in several
forms. We can also add hyperlinks to other Web pages both on our local
disk or on the Internet. Microsoft Office, which includes PowerPoint, Word,
and Excel are predominant in many business environments and these ap-
lications also support HTML format for presentations.

Whether we use PowerPoint or a Web Composer, the presentation will
require a reasonable amount of time to prepare and to rehearse. This is
not a five-minute job.
Methodological Aspects

The aim of this chapter is to provide the reader with an overview of some standard techniques that are commonly used in statistical consulting. In keeping with spirit of this book the emphasis of our presentation is on the client's perspective rather than the technical details of the methods. Appendix C does provide some technical details and tables, but a more comprehensive exposition of these methods may be found elsewhere. We provide references to the methods we discuss and an overview of statistical software is provided at the end of this chapter.

Of course, before we can apply any statistical procedure we need some data. Hence, we begin by looking at methods for collecting data.

3.1 Data Collection

There are several methods that can be used to collect data, but in order to draw valid conclusions it is important to collect "good" data. Unfortunately, many clients seek the advice of a statistical consultant after the data have already been collected. This is largely our fault, of course. As statisticians, we are often guilty of focusing on technique and not emphasizing the important role that a statistical consultant can have during the design stage of a statistical investigation. Having said that, a client is clearly entitled to know what are the advantages of getting a consultant's advice during the planning phase of a project. Chatfield (1995) lists three compo-
nents of a planned study where the advice of a statistical consultant can be particularly useful:

- Identify the important variables.
- Clarify the objectives of the study.
- Formulate the statistical problem.

The objectives of a project need to be well formulated in order for the conclusions to have a meaningful interpretation. This requires specifying the “right” objectives for a client’s project which is not always easy to do. The consultant needs to be careful not to end up giving the client the right answer to the wrong question. This is sometimes referred to as a “Type III Error” or an error of the third kind (Kimball 1957). We have addressed these issues in the previous chapter in terms of verbally interacting with the client during a consultation session and now turn our attention to the data collection process itself.

Data Collection Methods

The data collection process and objectives of a study may not always fall into the traditional distinction of a designed experiment versus an observational study. While it is certainly helpful to distinguish between the basic concepts associated with these data collection methods, there is a tendency for statisticians to be somewhat skeptical of conclusions based on observational studies. This is not without reason. Treatment effects in a well-designed experiment have a clear interpretation whereas observational studies often involve subjective responses that can be difficult to quantify and interpret. Hence, interesting effects that emerge from an observational study may not necessarily be real.

We briefly consider the following types of data collection methods that a statistical consultant would commonly encounter.

- Observational Studies
- Sample Surveys
- Longitudinal Studies
- Clinical Trials
- Designed Experiments

Observational Studies

In an observational study, the investigator generally takes a passive role and simply observes a certain cohort of subjects and collects the responses. While the word “passive” may not be the first adjective that comes to mind when we have been confronted by yet another telemarketer, the solicitation process is effectively the result of an observational study: a profile analysis based on an existing database consisting of information related to our spending habits, demographics, Internet usage, and so on. The objective of the profile analysis is to identify a large source of potential respondents since even a small percentage of positive outcomes can be profitable. See Cochran (1983) for further details on the planning and analysis of observational studies.

Protocol

As the telemarketing example suggests, the data collection process and analysis involved in observational studies can be quite extensive. In larger studies, it is often necessary to have a written protocol. This is because most (if not all) of the data collection will be administered by people with no statistical training. In a sample survey, for example, the “interviewer” needs to know what to do when a designated respondent is unavailable — is the interviewer required to call back later? If so, when and how many times? The written protocol must therefore provide detailed instructions on every aspect of the data collection process. The purpose of a protocol is to try to control nonrandom errors.

Sample Surveys

Sample surveys and polls have become increasingly common and are used extensively in market research. Although the concept and importance of selecting a random sample is generally well understood, the response rate from many surveys can be very poor. In some cases, the results may also be of low quality. A good design format is therefore important to help maximize the response rate and improve the quality of the data collected. Well-designed sample surveys provide a cost-effective method for estimating population characteristics accurately. Here, we summarize some of the main areas of concern in sample surveys, beginning with the following reminder:

Accuracy is not guaranteed from an individual sample.

That is, no matter how well designed and implemented a sample survey is, we are always subject to the profile represented by the (individual) sample we collect. Cochran (1977) is a classic text on the statistical theory associated with sampling methods. Dillman (1978), Thompson (1992), and Fink (1995) are other texts that deal with survey sampling methods.
Design Format  The design format of a survey is very important since it can have a large impact on the quality of data collected. Questions need to be simple and clear to avoid interpretation problems. Make it easy for the respondent to answer a question, or not answer. Non-responses need to be distinguishable from a category such as "Not Applicable." Perhaps more important, do not try to ask too much.

Sampling Method  The purpose of a sample is to infer something about a population and a random sample is necessary to ensure the statistical validity of the results. Simple random sampling (SRS) can be shown to be an optimal sampling strategy (Cochran 1977), but this is usually impractical to apply directly. The method of sampling needs to be consistent with the desired population profile, but must also satisfy practical overheads such as time and cost. Some standard sampling schemes are indicated below.

SRS Simple random sampling is equivalent to drawing names out of a hat without replacement. That is, every unit in the designated population has an equal chance of being selected. In most sample survey schemes, SRS is primarily used within subgroups identified in the population.

Stratification To avoid oversampling groups (strata) that dominate a population, stratified random sampling may be used based on the relative proportions of the strata present in the population. The population strata proportions need to be known in advance (or estimated from a pilot survey) and SRS would be used to select a sample within each stratum.

Cluster Randomly sampling across an entire population or stratum is often impractical. Instead, homogeneous clusters such as towns are first identified and a random sample (using SRS) of these clusters is selected to generate the final sample.

Multistage With large and diverse populations, several stages of clustering and stratification may be required to generate a cost-effective sample.

Multiphase Pilot studies, followups, and double sampling schemes can be used to optimize or adjust the overall sample size. Double sampling is often employed in situations where the quantity of interest (population parameter) need only be estimated to a certain precision.

Sample Size  The purpose of a sample is to estimate some parameter of interest associated with the population. The precision of the sample estimate (statistic) depends on sample size through its sample variance. In practice, real costs are involved in collecting survey data and these increase with sample size. A trade-off between cost and precision is usually required.

Implementation  The key to obtaining a valid sample is random selection and to avoid selection bias, random numbers are used. Biased results arise when the sample profile differs from the desired population profile. Nonresponse and undercoverage are two common sources of bias that can be partially reduced using followup surveys. However, even the phrasing of a question can have a substantial influence on the response — leading questions are frequently used to help promote political positions and market products.

Longitudinal Studies

A more specialized type of observational study involves the collection of longitudinal data. This is where each unit in the sample cohort is measured on several occasions over a period of time. The texts by Plewis (1985) and Selvin (1996) deal with the statistical analysis of longitudinal data. The purpose of this type of study is to assess the effect of an explanatory variable $X$ on a response variable $Y$ under controlled conditions. A typical application would be:

Example 3.1  What are the side-effects of a particular drug?

The side-effects associated with a drug may only develop with long-term usage and may also depend on the dosage amount. In this case, a carefully selected group of individuals would be followed over a period of time and the effect of dosage ($X$) on various side-effects ($Y$s) would be observed.

If the $X$ and $Y$ records are obtained from historical data, then the longitudinal study is said to be retrospective. Retrospective studies clearly depend on the quality of the historical data, but have the advantage that the problem of interest can be immediately analyzed. When the $Y$ is to be generated by the study, it is said to be prospective. Examples are presented below.

Retrospective  The response variable $Y$ is known from historical data and the effect of the explanatory variable $X$ is of interest: 50 smokers and 50 nonsmokers are retrospectively classified by age at death.

Prospective  The levels of the explanatory variable $X$ are fixed at the start of the study and the future values of the response variable $Y$ are of interest: 50 smokers and 50 nonsmokers are selected for a longitudinal study of the incidence of lung cancer.
Clinical Trials

Clinical trials were discussed in Chapter 1 in terms of the development and testing of drugs by the pharmaceutical industry. The full-scale testing conducted in Phase III studies is usually what is meant when a client or statistician refers to a clinical trial. Fleiss (1986), Pocock (1983), Meinert (1986), and Friedman et al. (1985) are texts that deal specifically with clinical trials. The key components of a clinical trial design are:

- Control group
- Written protocol
- Randomization

Control The control group consists of patients who receive the standard treatment or a placebo. A placebo is a “fake” version of the drug that is administered to patients in the treatment group. It contains purely inert substances and provides the investigator with a measure of the so-called “placebo effect” associated with the psychological influence of taking medicine. There may be several treatment groups employed to assess the efficacy of the real drug at different dosages.

Protocol Phase III clinical trials can typically involve a thousand or more patients spread out across many testing sites. In some studies, these sites may even be in different countries. The administration of clinical trials is therefore quite complex and, as we indicated above, the data collection process will be performed mostly by nurses, doctors, and other personnel who do not have any formal statistical training. In this situation, a written protocol is essential since deviations from the protocol are almost certain to occur. For example, a patient may need to be taken off the drug temporarily due to food poisoning or a patient may not follow the proper regimen for taking the drug. Similarly, deviations may also arise due to administrative personnel not following standard procedures correctly.

The written protocol for a clinical trial documents all information related to the study. This would include items such as

- The purpose of the study and the eligibility requirements for a patient to be included in the study.
- The sample size and method of assigning patients to the control and treatment groups.
- The treatment schedule and procedures for evaluating the patient’s response. The training required to use certain evaluation instruments.

- Decision procedures to deal with protocol deviations.

The raw information from the study is usually collected on a form that is filled out by the person evaluating the patient’s response. Some forms may contain several pages of information which all need to be entered into an electronic database. A good design format is desirable to help ensure the quality of data obtained during the data collection process.

Randomization The randomization of the treatment levels to patients is particularly important from a statistical perspective since this is the only objective method to counter potential sources of bias. However, randomization by itself is not enough to remove nonrandom sources of bias such as the doctor who “knows” what treatment a patient is receiving. The doctor may provide excellent care to all the patients in the study, but clearly won’t be looking for any treatment effect from a patient receiving the placebo. A double-blind implementation where both the patient and doctor do not know which treatment the patient is receiving can be employed to overcome this problem.

Randomized drug trials have certainly proved to be very effective for assessing new treatments, but they also pose certain ethical issues. Is it really fair to allow patients in the control group to go untreated? This question is made considerably more difficult when the patient has a disease or virus that would be fatal if left untreated. The statistical answer is that a control group is needed for comparative purposes. The ethical question clearly does not have an easy answer.

Designed Experiments

The last data collection method we consider concerns studies based on experimental designs. In these investigations, the effect of one or more treatments on a response variable is of interest. In Section 3.7 we revisit the statistical design of experiments and consider some specific designs that are commonly used in practice. The practical application of experimental design is emphasized in the text by Box et al. (1978). (This should be on every statistical consultant’s bookshelf.) The basic principles of statistical design of experiments are listed below.

- Control
- Randomization
- Replication
Control The importance of the control group and randomized assignment of treatments to patients in clinical trials was discussed above. Comparing several treatments is the simplest application of the principle of control. More generally, it refers to the problem of eliminating sources of systematic error (bias) and controlling for the effects of other variables on the response. Blocking factors, for example, exploit natural groupings of the observations. By controlling for the between-block variation in an experimental design, a more precise comparison of the treatment means is possible.

Randomization The main advantage of well designed experiments over observational studies is that experiments can provide good evidence for causation. By controlling for other factors and eliminating bias, differences in the observed response can be attributed to the effect of the treatment. By removing the subjective judgment of the investigator and making the assignment of subjects to treatment groups independent of any characteristic of the experimental units, randomization relies on chance alone to create comparative groups. A completely randomized design is not necessarily practical or even desirable (e.g., blocking). Some form of restricted randomization is needed in this situation.

Replication This is not an issue in clinical trials, but not every branch of science has the budget required of pharmaceutical companies. Indeed, the purpose of many experimental designs is to provide the investigator with an efficient method to analyze the effect of several treatments simultaneously. That is, the total number of treatment combinations or runs that need to be performed can be kept to a minimum. (We defer a more formal description of these designs until later in this chapter.) However, replication of at least some runs is required in order to assess experimental error. As always, there is a trade-off between sample size (number of runs) and precision (sensitivity of experiment to detect treatment differences) which the investigator must face. The role of a statistical consultant is to provide guidance on selecting a suitable compromise.

Occasionally, the consultant may encounter the problem of pseudo-replication (Hurlbert 1984). To study regrowth after a forest fire, the number of new seedlings per square meter is counted at a particular location. If the counts from 10 square meter blocks are obtained, do we have 10 replicates? Chatfield (1995) provides a similar example involving a decomposition study of several bags of leaves in a pond.

3.2 Data Processing

Now that the database has been collected and transferred to electronic format it will need to be read into the statistical software program. Here we assume that the data transfer to our system has been successfully completed and the database for the project now resides on our system in appropriate format.

Always make a backup copy of the original database.

(Details concerning these issues are addressed later in this chapter.) The first stage of our statistical analysis begins with Data Processing. Thus, our first task is to read the data into our statistical software program and perform an initial assessment of the data quality.

Data Quality

The three main steps for assessing initial data quality are:

- Backup — Make a backup copy of the original data.
- Format — Codes and data types for reading the data.
3. Methodological Aspects

- Values — The data entries associated with the variables.

Backup Keeping a copy of the original data serves several purposes. It provides the standard precautionary measure in case our working data file gets corrupted or deleted — this can happen at any time, often without warning, and we may be completely powerless to stop it (e.g., a bad drive wipes the disk, we mistakenly type `rm *` on a UNIX machine, etc.). It allows us to communicate problems with data in the format that the client knows. Line 53 in our (sorted) working data file may be quite different from that of the original. Similarly, it allows us to compare specific entries in our working dataset with those of the original. This can be particularly helpful when trying to resolve input errors.

Format Statistical software packages such as SAS and S-PLUS require format statements in order to read a data file correctly. For example, character variables need to be declared properly in SAS and data tables are assumed to be rectangular in S-PLUS. Problems often arise when the original data contain missing values that are represented by blank spaces (such as an empty cell in an Excel spreadsheet). Since the default is to ignore blank spaces, the remaining data entries become assigned to the wrong variable. In some cases it may be easier to edit certain aspects of the data file (our working copy) rather than try to employ complex format statements. Alternatively, it may be possible to read in the data file with a proxy format (as character variables, for example), then output the data in the desired format. Of course, providing clear instructions to our client as to the type of format we expect their data file to appear in, can certainly help reduce the amount of time we need to spend on this activity.

Values Once the data appear to have been read correctly, the next step is to check the statistical quality of the data. This includes detecting obvious or potential errors in the data values themselves. Summary statistics and frequency tables provide a useful way to isolate and assess potential errors. Some examples are presented below.

We should emphasize that an assessment of data quality also applies in the case where the clients have assumed responsibility for performing the statistical analysis using their own software. In this situation we should carefully examine the summary statistics associated with the client’s data processing, checking for the type of potential errors or problems we discuss below. This needs to be done before we provide the client with assistance on the interpretation of the results — remember that inferences based on invalid data are rather meaningless. A more succinct expression for this scenario is “garbage in, garbage out.”

<table>
<thead>
<tr>
<th>Potential Error</th>
<th>Possible Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Some categorical classes contain very few observations</td>
<td>Data entry error</td>
</tr>
<tr>
<td>A categorical variable contains more levels than it should</td>
<td>Changes in coding used</td>
</tr>
<tr>
<td>Variables that contain a high proportion of missing values</td>
<td>Wrong format used in read-in</td>
</tr>
<tr>
<td>Programming error</td>
<td></td>
</tr>
<tr>
<td>Values associated with user-defined variables do not make sense</td>
<td>Data entry error</td>
</tr>
<tr>
<td>Illegal operation performed</td>
<td></td>
</tr>
<tr>
<td>Values that lie outside the expected or allowable range of a variable</td>
<td>Outlier: data entry error</td>
</tr>
<tr>
<td>Poor quality data</td>
<td></td>
</tr>
</tbody>
</table>

1. Classes of a categorical variable that contain very few observations.
   This may simply be a typing error that results in a nonexistent class being created for a categorical variable. If not, then it may be necessary to combine classes or exclude that class from the analysis.

2. Changes in the coding used for the classes of a categorical variable.
   Categorical variables whose classes have been numerically encoded tend to be more susceptible to miscoding errors. Although numerical values are easier to enter for categorical variables, it can be difficult and time consuming to diagnose systematic errors. In cases where a variable has more levels than it should, a careful check is needed to ensure that the data are being read correctly (e.g., 30 .0 will result in 0 being assigned, incorrectly, to the next variable).

3. Data values that lie outside the expected or allowable range.
   A quick check of the summary statistics (min, max, mean, standard deviation) can indicate potential errors for continuous variables. Obvious errors are usually revealed as gross outliers. A large standard deviation should also be regarded as suspicious, particularly when it is of similar magnitude to the mean. ID and count variables can be checked via frequency tabulations. (There should be a frequency count of 1 for each ID label.)

4. Variables that contain a high proportion of missing values.
   This can occur if a column-shift has occurred due to a blank space, since character values are set to missing if the next variable is declared as continuous.
If the client has preprocessed the data and provided us with variables computed from other quantities, we should use our software to compute the same quantity and check for mismatches.

**Missing Values and Errors**

There are several important issues that arise when the database contains missing values or errors. In some cases, the impact on a statistical analysis can be substantial and simply ignoring missing values in textbook fashion is not recommended! Similarly, decisions need to be made regarding errors that remain after the data have been processed. Again, simply assigning a missing value to any identified error may not be the best approach. The following provides a list of some situations where errors and missing values typically occur.

**Data Collection**
- Misreading a measurement
- Misrecording a measurement (20 instead of 2.0)
- Estimating a measurement
- Faulty apparatus used in study
- Different instruments or personnel used in the study
- Truncation or biased rounding of measurements

**Data Entry**
- Mistyping values during transcription to electronic format
- Misrepresenting data values
- Duplication of values in columns or rows
- Misalignment of values in column or rows
- Incorrectly assigning values as missing
- Assigning a value when observation was missing

The main issue that arises with errors and missing values is that there is a loss of information. In statistical terms, this corresponds to a loss of degrees of freedom and hence, less reliable inference. The first step is therefore to work with the client and try to recover these data where practical. Having the client define precisely how certain variables were recorded and entered is often a useful place to start the recovery.

We may be surprised how our “explicit” instructions concerning data entry, coding, and formats were not quite as clear as we thought. Do not blame the client. They would have done their best to do what we asked — this is our turn to learn from experience.¹

Once the recovery from the original data source has been effectively exhausted, decisions need to be made with regard to the remaining errors and missing values. At this point we should emphasize that only “potential” errors actually remain since the correct value cannot be recovered from the original source. The difficulty here is that there is a tendency for the analyst to make ad hoc decisions such as setting all remaining “potential” errors to be missing, or dropping an entire multivariate observation even if only one component is missing. On the other hand, when a value is clearly an error (e.g., it lies outside the allowable range), modifying an error or missing data value is clearly a subjective decision and introduces bias (or worse) into the analysis. This includes the often-used practice of setting a missing value to the mean or median of the data associated with the variable. A more objective approach to imputing missing values is described in Little and Rubin (1987).

### 3.3 Statistical Issues

Having completed the data processing phase of the project, the investigator is now ready to perform a “statistical analysis” of the data. Even in relatively simple projects, this would typically consist of:

1. Computing numerical summaries and graphical displays
2. Performing a statistical “test” on the data
3. Interpreting the results and making conclusions.

The last item usually presents the greatest difficulty for clients since this involves the concept of statistical inference. The theoretical foundations underlying statistical methodology are extensive and reside within the domain of expertise of the statistical consultant — keep them there! The client came to us for assistance, not a course on probability and inference theory. Of course, the issue of statistical inference is important and needs to be addressed. We consider some of the issues with respect to the following areas of inference.

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¹One way to help avoid these types of misunderstandings is to actually sit with the client and enter some example cases. The client can then see what we really mean about binary coding and distinguishing missing values.
Estimation

A summary statistic such as the sample mean $\bar{X}$ is an example of a point estimate that can be used to infer something about the unknown mean ($\mu$) of the population from which the sample was drawn. While this statement may seem relatively innocuous, it rests on top of a rather considerable amount of estimation theory. The “inference” about the population parameter $\mu$ is based on the properties of the sample mean estimator: the theoretical random variable quantity defined prior to the experiment ... and about now, we probably just lost the client! What the client really needs to know is what type of estimation method is appropriate for the project. The following examples are used to illustrate this point.

Example 3.2 The average AGE of a patient

Databases provide the date of birth of a patient, but not necessarily a corresponding AGE variable. The difference between the current date and the patient’s date of birth can be used to compute a truncated version of AGE in whole years.

The problem with using a truncated version of AGE is that when the average AGE is computed, how should a value such as 68.75 years be interpreted? While this “looks” like the average age is 3 months shy of 69 years, the association of “months” with the fractional year part (0.75) is misleading since it was derived from a truncated AGE measure that does not reflect a patient’s age in terms of months. That is, it clearly underestimates the average age of the patient cohort since the fractional year component (months + days) of an individual is not included.

Example 3.3 Normal blood pressure

The “normal” blood pressure for a person is often quoted as a range.

In this situation, an interval estimate is a more appropriate measure of the normal blood pressure for a person. A single point estimate such as the mean value clearly does not convey the information a person needs if their blood pressure happens to be higher than this “normal” mean value.

Remarks

1. The two simple examples above are not the only types of estimation problems that the consultant will encounter. An interesting example is given in Thisted (1988) where the E-M algorithm (Dempster et al. 1977) was employed to estimate the proportion associated with a mixed distribution. This is known as the “Widows” dataset where the mixing proportion of the Poisson and binomial distributions needs to be estimated for the “zero” counts: widows with no dependent children.

2. In some cases, the asymptotic normal theory that is often employed to derive standard errors may not hold. In this case, resampling methods (discussed later) can be employed to generate standard errors and confidence intervals. The client may need some convincing that this is “allowed” and perhaps more important, the client needs to understand that resampling methods do not make the sample “larger” than it is.

Hypothesis Tests

The aim of a statistical inference procedure is to enable the analyst to make conclusions about the problem under investigation based on the experimental evidence. In traditional applications of statistical inference, the analysis of a problem involves several components. First, the problem needs to be described in mathematical terms, which serves to identify the nature of the randomness. Some simplification of the precise nature of the randomness is often necessary in order to make the analysis tractable.

Having translated the problem into a “random process,” the next step is to select a suitable statistical procedure for evaluating the experimental evidence. Here, the choice of procedure is dependent on both the context of the problem and the type of evidence to be evaluated. Matching this information with an appropriate probability model provides the analyst with a procedure that can be used to measure the likelihood of any outcome from the experiment. However, in order to compute the correct probability of an actual outcome, the “true” state of the random process needs to be represented by the model. Clearly, if this were known, statistical inference would not be needed. Thus, the following strategy can be employed.

1. The analyst makes a “hypothesis” about the true state of the process and then evaluates the probability of obtaining the outcome reported from the experiment, under this assumption.

2. Should this computed probability seem too unlikely, it is reasonable to infer that the stated hypothesis was incorrect.
3. In this case, the analyst would conclude that the evidence does not appear to support the hypothesis that was assumed.

This "conclusion" and associated hypothesis are dependent on the context of the problem. In summary, the stages involved in this type of statistical inference procedure are:

**Assumptions** Statistical procedures require certain assumptions to be made about the "random process" under study. These assumptions enable a probability model to be derived that mathematically describes the random process. The experimental evidence is then analyzed on the basis of this model.

**Hypothesis** In the hypothesis testing approach to statistical inference, the evidence is assumed to have occurred when the experiment was performed under a particular condition. This is referred to as the null hypothesis ($H_0$). Under $H_0$, the probability of obtaining a result at least as "unlikely" as the observed outcome from the experiment is computed from the probability model. The computed probability is called the $P$-value and will depend on the form of the alternative hypothesis ($H_1$) of the hypothesis test. However, if the $P$-value is less than $5\%$, then $H_0$ may be rejected in favor of $H_1$. In this case, the result of the hypothesis test is said to be statistically significant.

**Conclusions** It is important to note that a statistically significant result from a hypothesis test does not imply causation. Indeed, the $P$-value provides a measure of the probability of making a Type I error: rejecting $H_0$ when it is true. We would need to repeat an experiment many times in order to establish causation. In practice, we usually do not have the opportunity to completely reproduce an experiment and need to make conclusions based on the results at hand. Considerable care is necessary when making conclusions based on a statistical inference procedure to ensure that unsubstantiated claims are not implicitly associated with the statistical nature of the analysis.

**Inference Aside**

Statistical inference is perhaps better described as a philosophy since there is considerable debate concerning the theoretical framework on which the above frequentist approach to inference is based. Indeed, there are philosophical problems involved in the very notion that we can assess probabilities and make inferences. This book is clearly not the place to address this issue, but it is important to note that there are other approaches to statistical inference. (We refer the reader to Barnett (1982) for a comparative account of the different approaches to statistical inference.) In particular, Bayesian inference combines "prior" information that we may have about the data (usually expressed in terms of a probability distribution) with the sample data which enables the "posterior" information to be evaluated.

In this book, we take the pragmatic view that for most practical purposes, the significance testing approach to statistical inference does work. (Provided, of course, it is performed correctly.) However, there are many situations where the Bayesian approach is intuitively more appealing. In market research, for example, our prior belief about the specified population for a new product should be incorporated in planning our test market survey. Statistical consultants therefore need to be flexible in their approach to statistical inference.

**Remarks**

1. The statistical emphasis that we have (deliberately) employed in summarizing the stages of a hypothesis test is more likely to convey an impression of arrogance on our part, than to further the client’s understanding of statistical inference. Although clients may be quite familiar with "performing" a hypothesis test, most would find this type of summary to be intractable.

2. So what approach should we take? If the client is already familiar with this type of statistical test procedure, then we can begin by emphasizing the importance of using the evidence to check whether the assumptions of the test are satisfied prior to drawing conclusions based on them. This would be followed by examining the contextual meaning of the stated hypothesis and, finally, making sure the client understands the limitations of a "statistical" conclusion.

3. For clients who are not familiar with statistical tests, the remark above still applies, but we have found it useful to precede this discussion with a simple example such as the following.

A stranger claims to have obtained 10 heads in 10 tosses of a coin. If the coin is assumed to be fair, then the likelihood of obtaining this outcome by chance alone is less than 1 in 1000. Since this is less than the minimum standard of 5%, we would conclude that the result is due to something other than chance. Accordingly, we might accuse the stranger of lying.

While this "conclusion" may seem quite reasonable, suppose we are given the opportunity to reproduce the experiment by tossing the coin in question ourselves. If we were to obtain 9 heads in 10 tosses, then our conclusion would agree with the statistical notion that the result is due to something other than chance. That is, we would reject the assumption that the coin is fair. However, the implication that the stranger is lying is clearly invalid.
4. Clients often state their objectives in terms of directional hypotheses. When translated into statistical notation, a directional hypothesis represents $H_1$. The problem is that the $P$-value provides a measure of the likelihood of the experimental outcome with respect to the null hypothesis $H_0$. The key point is that a decision can be made about the client's directional hypothesis based on the $P$-value associated with the statistical test. Here, it is usually the case that the client needs help with the conclusion.

5. It is often instructive to consider the conclusion that would be associated with a nonsignificant test result. In some fields of study, the 5% cutoff is set in stone. (Even a result such as 0.052 would be ignored!) This is unfortunate, but we should at least try to convince clients about the fallacy of adopting a strict cutoff — perhaps they can begin to change the attitude of their peers. One way to do this is to consider the power of the test. This may need to be done indirectly at first (starting with the relationship between sample size and the “reliability” of a test), but providing the client with a new type of “$P$-value” (power) and a statement of what the number means, can be useful. The issue of sample size and power is discussed next.

**Sample Size and Power**

Determining an appropriate sample size is an important concern in observational studies and planned experiments. It is directly related to the cost of implementing the study and affects the quality of the statistical inference associated with the results. Methods for sample size determination address the problem of optimizing the amount of information that needs to be collected with respect to a particular application. Some examples are:

**Longitudinal Studies** How long should the study run and how often should the data be collected?

**Sample Surveys** In complex surveys, cost functions need to be optimized with respect to quality to ensure maximal return of information.

**Clinical Trials** The effect of a new drug needs to satisfy certain government regulations. How many patients are required in each treatment level and for the control group?

**Quality Assurance** Inspection schedules and sampling schemes need to satisfy quality protocols.

**Experimental Designs** How many items per cell are required in a particular design to detect a specified difference in the effects?

In general, an appropriate sample size can be obtained by specifying a level of accuracy or by maximizing a specified objective function. Explicit methods exist for many standard problems and comprehensive table-based on power analysis are available: Kraemer and Thiemann (1987), Cohen (1988), and Desu and Raghavarao (1990) are three key monographs. For a review of sample size determination methods, including Bayesian approaches, see Adcock (1997). Power analysis is also incorporated into a number of statistical software packages.

In practice, however, determining an appropriate sample for the client may be quite difficult. Consider, for example, the following definition of power $= 1 - \beta$, where $\beta = P\{\text{Type II error}\}$.

The **power** is the probability of obtaining a significant result. It is a function of the sample size $n$, the effect-size $\delta$, the standard deviation $\sigma$, and the significance level $\alpha$. The power tells you how likely it is that your experiment will detect a specified difference $\delta$ at a given significance level $\alpha$.

Determining the sample size $n$ therefore involves specifying each of the other quantities. Conventional values for the level of significance and power are 5% and 80%, respectively. In many standard tests, $\sigma$ can often be absorbed to give standardized effect-sizes. Otherwise modifications in the sample size computations are necessary to account for the variability associated with estimating $\sigma$. The main problem occurs in trying to specify a reasonable effect-size since this represents the degree to which an investigator believes the null hypothesis ($H_0$) to be false. This is a subjective decision and is further complicated by the different scales of measurement involved since effect-size depends on the type of test used.

In the behavioral sciences, tables (see, for example, Cohen (1988, 1992)) to determine sample size are often based on classifying effect-sizes as small, medium, and large for certain tests. In engineering and quality assurance applications, sensible sample sizes are often well established and the operating characteristic (OC) curve is used to assess $\beta$ versus standardized effect-sizes. The OC curve is simply a plot of $\beta$ versus $\delta$ for a given sample size $n$. An OC chart consists of overlaid curves at several different sample sizes. For simple experiments and designs, these tables and OC charts are usually sufficient for the purposes of sample size determination. We conclude with some additional comments.

1. Explaining to a client the concepts involved in power analysis can be very difficult. Adopting a confidence interval approach may be more effective. For example, the conservative margin of error calculation $2\sqrt{p(1-p)}/n \leq 1/\sqrt{n}$ that is used in opinion polls is an easy way to familiarize a client with the issue of sample size versus quality.

2. Power calculations are performed prior to the experiment. They do not explain why a postexperiment result is not significant.