WRITING SUCCESSFUL SCIENCE PROPOSALS

THIRD EDITION

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Yale UNIVERSITY PRESS/NEW HAVEN & LONDON

First edition published 2000. Second edition 2009. Third edition 2018.

Set in Scala type by Newgen North America.
Printed in the United States of America.

Library of Congress Control Number: 2017963808
ISBN 978-0-300-22670-6 (pbk. : alk. paper)

A catalogue record for this book is available from the British Library.

This paper meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).

10 9 8 7 6 5 4 3 2 1

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Preface

Research proposals combine every aspect of scientific inquiry, from creative conceptualization to detailed design, projected analysis of the data, synthesis of the results, and estimation of the budget. Because grant applications are an articulation of the scientific process, writing them is one of the most challenging and exciting parts of "doing science." If you are planning to write a grant application for a government or private foundation, or if you are writing a proposal to conduct research as a graduate student or undergraduate, this book will help you through the process.

This book provides guidance for those conceptualizing and formulating their research plans, and it offers specific instruction on organizing and presenting material in a standard format. We offer an overall organizational framework, and we list the components of successful scientific proposals. Research proposals are written for a variety of purposes and are submitted to many different agencies and to faculty

committees. We focus on agencies that solicit proposals in the natural sciences; these include the National Science Foundation (NSF), National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), U.S. Forest Service (USFS), U.S. Geological Survey (USGS), and private corporations and foundations, as well as academic committees. Our format should also be useful to those submitting to the National Research Council of Canada, the NATO Scientific and Environmental Affairs Division, the European Research Council, the Natural Environment Research Council of the UK, and other funding agencies worldwide.

This book began as a course for graduate students at Dartmouth College. Given the importance of scientific project design and proposal writing to future scientists, the faculty in ecology and environmental studies at Dartmouth College designed a course on the topic. When two of the authors, Andrew Friedland and Carol Folt, began teaching this course in 1994, they could not find a text that specifically addressed grant writing in the natural sciences. So they decided to write one based on their experiences in the classroom. The first edition was published in 2000. They continued teaching the course at Dartmouth College through the next decade and in that time received feedback from readers and students affirming that the need for reference works on proposal writing had grown even stronger. The second

edition was published in 2009 with updates and expanded information on formatting, electronic submission, seeking matching funds, and federal requirements. It included new chapters on writing proposals for private foundations and on multidisciplinary, multi-investigator proposals. Now, nearly two decades since the first edition was published, the authors are excited to release a third edition.

For this edition they welcome co-author Jennifer Mercer. At the time of the publication of the first edition, Jennifer was pursuing her PhD, and at one point she was Andrew's teaching assistant. She eventually went on to become a research scientist and is now a program manager overseeing science grant awards. She brings a wealth of additional experience to the team.

This edition is fully updated and expanded. We paid particular attention to:

- Identifying funding opportunities
- Contacting program officers
- Writing project summaries
- Presenting results from prior agency support
- Developing broader impacts by going beyond the science and toward the societal benefits of the research
- Considering how proposals are evaluated in the review process

We introduce several new topics:

- Concept papers
- Data management plans
- Project management plans
- Crowdfunding

In addition, each chapter now opens with a quote from an experienced proposal writer, reviewer, or administrator. We also include a list of key points and homework assignments at the end of each chapter. The homework is designed to help you tackle the proposal writing process one step at a time. Even with all the new information, we have worked to maintain the brevity of the first and second editions.

Not only should modern scientists have the ability to write successful research proposals, but introducing students to the process of doing science as early as possible in their training improves the quality of their learning. Many research institutions now offer graduate-level courses on proposal development, and research design continues to grow as an element of undergraduate science curricula. We hope that our book is of value not only to students and new researchers writing their first proposals but also to experienced proposal writers seeking to improve their skills.

Acknowledgments

We are grateful to the many students, colleagues, advisors, reviewers, and program managers who have contributed to our proposals over the years, as well as those who have helped directly with this project. While we were writing this book, numerous people generously shared ideas, experiences, and proposals with us, including John Aber, Victor Ambros, William Ambrose, Steve Anderson, Matt Ayres, Joel Blum, Doug Bolger, Christine Bothe, Rick Boyce, Patricia Brennan, C. Page Chamberlain, Margaret Dyer Chamberlain, Celia Chen, Justin Chen, Ann Clark, Lisa Clay, Jim Coleman, Jack Dibb, Charles E. Dunlap, Celia Elliott, Hany Farid, David Finnegan, Marcelo Gleiser, Mary Lou Guerinot, Nelson Hairston, Jr., Robert Hawley, Dick Holmes, Mary Hudson, Tom Jack, Lars Kalnajs, Sora Kim, James Kinsey, Kevin Kirk, Jon Kull, Eric Lambie, Carrie Larabee, Jane Lipson, Frank Magilligan, Pat McDowell, Mark McPeek, Eric Miller, Susan Milord, William North, Jerry Nunnally,

Jonathan O'Donnnell, George O'Toole, Bonnie Paton, David Peart, Stephen C. Peters, Marjorie Piechowski, Bill Reiners, David B. Resnik, Jim Reynolds, Roger Smith, Michael J. Spires, Richard Stemberger, Judy Stern, Amy Stockman, Ross Virginia, Richard Wright, Wayne Wurtsbaugh, Ruth Yanai, and our anonymous reviewers. We are also grateful to Lacy Cleveland, Aliette Frank, Peter Groffman, Jill Mikucki, and Laura Ogden for providing thorough reviews of the second edition before we began writing the third edition. Special thanks to Zoe Courville for reviewing several draft chapters of the third edition and to Camellia Pham for providing a full tutorial on private foundation funding. We especially thank all the professionals who provided thoughts and comments for the opening quotes. All the others who helped along the way we thank as well, with apologies if we have omitted anyone's name inadvertently. Our special recognition goes to our dear colleagues Noel Perrin and Donella Meadows, both of whom have passed away since the first edition was published. Their advice for navigating the publishing world was invaluable. We would also like to recognize Gordon Hamilton, who passed away before the third edition was finished. Gordon provided invaluable insight and facilitated introductions so we could learn more about private foundation funding.

We are especially grateful to Rebecca Kohn, our development editor, and Leah Kohn, who proofread the third

edition. We also thank Bob Land and Catherine Rocchi. We thank Eva Skewes, Mary Pasti, Joseph Calamia, and Jean Thomson Black for their support, enthusiasm, and hard work as our editors at Yale University Press. We thank Mark Litzler for updated cartoons for the third edition and Doug Harp for designing cover images.

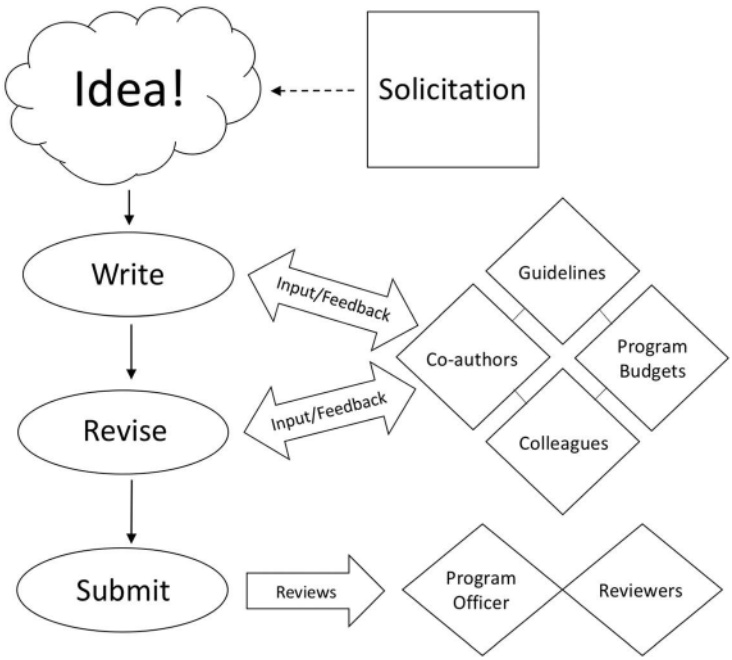
We also wish to acknowledge the many users of our book who have contributed important input, feedback, and encouragement. Andrew Friedland would like to thank Richard and Jane Pearl for friendship and support over the past decade as well as the Dartmouth College Arts and Sciences Dean of the Faculty Office for financial support. Finally, we thank our families, who have endured the many days we spent writing proposals and writing a book about writing proposals.

A Note to the Reader

> Almost all good writing begins with terrible first efforts. You need to start somewhere.
>
> —Anne Lamott, *Bird by Bird: Some Instructions on Writing and Life*

When it comes to writing science proposals, figuring out where to start is always a challenge. We wrote this book to be read two ways: either in its entirety before beginning to write a proposal or chapter by chapter—but not necessarily in sequence—as you develop specific sections of your proposal.

The schematic shown here illustrates the steps of proposal development and writing. You begin with an idea, but sometimes a solicitation (or request for proposals) from a particular agency can provide motivation. There are many steps between the formation of this initial idea and successfully obtaining funding to conduct your research. The process is an iterative one that allows your co-authors,



colleagues, reviewers, and funding agency personnel to provide input that you will use to refine and even revise the proposal. Agency guidelines and budgetary restrictions will also influence the development of your proposal. Once you have reconciled all input and feedback, you submit the final document.

The process may seem simple, but over years of developing our own research proposals and teaching our course, Design and Development of Scientific Proposals, we've identified several common areas in which researchers often struggle

when it comes to writing successful research proposals. Using this book to hone your skills will improve your ability to:

- Identify and describe the conceptual framework of the research question
- Review the relevant literature, both theoretical and empirical, on the system to be studied and any systems related to it
- Describe a general research question in the context of the conceptual framework and the theoretical and empirical work that precedes the proposed work
- Formulate a concise and incisive set of hypotheses or specific aims to address the overarching question
- Design studies to test each hypothesis or aim
- Develop methods and techniques to test, analyze, and synthesize results
- Evaluate potential alternative outcomes that may be obtained from each part of the study and consider where each of these alternatives may lead
- Combine these items—framework, literature review, hypotheses, etc.—into a coherent, precise, concise, and exciting proposal
- Submit the proposal to the appropriate agency or evaluation committee

- Interpret and respond constructively to reviews of the proposal

The chapters in this book address these common areas of difficulty and provide detailed guidelines for writing grant applications. We present the material in much the same order we have used in teaching our course and in designing our own research proposals. Although we focus on research proposals for the natural sciences, the process and logic presented here apply to a variety of disciplines, including those in the social sciences.

In Chapters 1 and 2 we discuss how to start writing a proposal, how to identify funding opportunities, and how to determine the roles of collaborating authors. In Chapter 3 we outline the basic elements and organization of a proposal. In Chapter 4 we consider the conceptual framework and how and where in the proposal to articulate succinctly the study's significance. In Chapters 5 through 13 we address the requirements and construction of the specific elements found in most standard proposals, such as title, summary, background, methods, and budget. We present the mechanics of submitting and tracking a proposal and revising and resubmitting it in Chapters 14 and 15. In Chapter 16 we discuss submitting proposals to private foundations. In Chapter 17 we look at the particular needs of multidisciplinary, multi-investigator proposals. In Chapter 18 we conclude the book with some thoughts about ethics and scientific research.

Each chapter contains a list of key points and suggested homework assignments or practice activities to reinforce the material covered. We kept the lists of key points short to help you retain the major ideas presented in each chapter. We designed the homework assignments so you can use them either in sequence while writing your proposal or chapter by chapter when you need practice with certain parts of the process. You may also find helpful the lists of additional resources and useful links located at the end of the book.

If you submit a proposal after using this book or if you use this book in a course, please let us know how you fare. We can be reached at wssp3e@gmail.com. We look forward to hearing from you and wish you great success with your science proposals.

CHAPTER 1

Getting Started

> Proposal writing is a genre, just like whodunits or romance novels. Each proposal should be crafted so that it tells a coherent, compelling story.
>
> —Michael J. Spires, Office of Contracts and Grants, University of Colorado-Boulder; and Board of Directors, National Organization of Research Development Professionals

For some scientists, designing research carries the same sense of exploration, anticipation, and unlimited opportunity as the first day of a new school year. For this reason, it can become a scientist's favorite endeavor. The need to develop precise, concise, well-articulated grant applications has also become more important than ever. The increase in specific requirements for proposals and the greater scrutiny they have come to receive have made proposal writing more demanding. It is our hope that it will continue to be a satisfying and educational experience for new as well as veteran proposal writers.

First Steps

As you begin your research proposal, we urge you to spend time reflecting.

- *Think big.* Reflect on your question from its broadest perspective. Imagine finding innovative solutions to fundamentally important problems. If you start small, your work will end up even smaller.
- *Avoid tunnel vision.* Consider projects that could lead to years of research. Enjoy a time of intense creativity, and—at least for a while—think beyond your immediate research area.
- *Dream.* Dream about solving important problems, making a difference, producing significant papers, and making discoveries.
- *Take your time.* Great ideas do not appear in a matter of hours or even a few days. When designing a research project, set aside as much time as possible for the project. You will need it.

Planning research can be stressful. We all have periods of insecurity, times when we mistakenly believe that everything rests on the outcome of one specific project. As researchers, we often fret about how our peers or advisors will evaluate our work. We worry about choosing the right research questions: "Will I think of a question important

enough to hold my interest and merit my attention for years to come?" And we feel uncertain about the outcome: "Will my research idea work?" "Will it lead to publications?" Most people experience anxiety when they feel pressured to identify research problems.

Reducing the uncertainty associated with developing a scientific proposal will help foster the excitement and innovation that lie at the heart of science and research design. Here are some simple steps to ease yourself into the process.

- *Define tasks associated with the proposal.* Don't make the list too long or too wide-ranging at the start, or you will be discouraged. Start with a master task list and plan to break down each task further at a later time. Examples of master tasks might include identifying funding opportunities, completing administrative tasks, developing a timeline, conducting background research, defining sections of an outline, and so on.
- *Involve your collaborators early.* Many proposals are collaborative with colleagues in either your own institution or other institutions. Different work habits, schedules, and institutional deadlines are important considerations and can affect your overall timeline.
- *Develop a timeline or strategy for working on your proposal.* Try working backward from your deadline to get

a reasonable idea about when specific tasks must be accomplished. If you are responding to a request for proposals (RFP) or a solicitation without a deadline, set one for yourself. Make sure you have sufficient time. It can be helpful to block off regular periods of time to dedicate to proposal writing, particularly if your workday schedule includes other time-consuming activities, like teaching, laboratory work, and meetings. If your most productive thinking and writing tends to occur at a particular period of the day, try to schedule several hours during that time to work on your proposal. This will allow you to maintain a steady pace and accomplish tasks on a regular basis.

- *Accomplish something early.* Complete a few tasks quickly. Using your master task list and timeline, separate tasks with short- and long-term deadlines and tackle some short-term items right away. A sense of early achievement will encourage you to move forward.

- *Remember that the best proposals are built from the best science. Effective proposals require a sound scientific basis.* Developing and then articulating a logical framework for a problem are the key elements in the success and power of a research proposal. Some researchers believe that the best problem solvers are individuals who

understand the need to get the initial question right, which is often difficult to do (Runco 1994; Proctor 2005). So time spent developing ideas is well spent.

- *Be prepared for change.* Nothing is fixed. You will think and rethink everything as you develop your proposal.
- *Take care of yourself.* Since you may write many proposals in the years to come, it is important to develop healthy habits early on so the process will continue to be satisfying and exciting.

Exercises for Getting Started

We recommend four exercises to initiate proposal development. These exercises are not meant to be accomplished in a single sitting but should be pursued concurrently.

EXERCISE 1.1. Critique other proposals. Established scientists routinely review the proposals of students and colleagues as part of the peer review process. This gives them a sense of the scope and size of the best research proposals, as well as insight into the most effective writing styles. Assessing other research proposals is also a potent method of learning science and focusing on both the broad implications of research and the methodology behind it. Reviewers, as a general policy, destroy proposals after reading them, but most scientists will share their own successful

and unsuccessful proposals with peers and students. Do not hesitate to request such assistance from colleagues or faculty in your department.

As you read proposals, consider, in general terms, the following major criteria and ask yourself whether the proposals are written in a way that effectively satisfies these criteria:

- Scientific content
- Innovation and scope of ideas and methods
- Structure and format
- Clarity
- Style

You should also consider the following points, which guide reviewers of proposals for the National Science Foundation (NSF) and other granting agencies:

- The scientific importance, or merit, of the question(s)
- The implications of the research for the community at large
- The rigor of the hypotheses or the testability of the study questions
- The feasibility of the research design
- The qualifications of the investigator(s)
- The suitability of the facilities for the proposed work

In the classroom, we begin with a discussion of proposals that we have written or that have been given to us by our colleagues to share with the group. Using the title, project summary (or abstract), and significance sections, we ask the class to question whether the author has convincingly justified the proposed work. We discuss methods, graphics, and style and ask whether the work captured our attention. At some point we try to compare each proposal with others we have read. This discussion is meant to be a starting point; eventually everyone develops individual styles, methods, and measures for evaluating proposals.

EXERCISE 1.2. Identify appropriate funding opportunities. You may already know where and to whom you'll be submitting your proposal. If so, that's great! If not, you'll need to spend some time searching for and identifying appropriate opportunities. Many researchers develop concept ideas and then watch for funding sources that might be a good fit. If you think big initially, your concept can likely be developed into a testable hypothesis (or hypotheses) that will fit the objectives of various RFPs. In addition, if your idea can be broken into smaller projects or phases, you may be able to secure a small seed grant that will get you started and help to strengthen the quality of your work for later proposals. There are several ways to find funding opportunities.

- Familiarize yourself with the funding cycles and grant types of the large federal agencies, including

NSF, National Aeronautics and Space Administration (NASA), National Institutes of Health (NIH), and Environmental Protection Agency (EPA). NSF often issues "Dear Colleague" letters to announce new solicitations. Read a few RFPs or solicitations from each of these agencies.

- Subscribe to newsletters and email distribution lists in your field; these often include announcements of funding opportunities. For example, NSF Update is a subscription email listserv that distributes information on funding opportunities.
- Investigate opportunities at your institution. Many universities have special funds to support research or procurement of instruments, and these are usually awarded competitively. Some institutions also offer matching fund opportunities to boost your project if you secure a small amount of outside funding.
- Network with colleagues and peers during fieldwork, on campus, at conferences, and online. Networking and cultivating relationships is particularly helpful when pursuing nonfederal grants because you will need to build interest in your work in order for a private entity to consider funding it.

EXERCISE 1.3. Accomplish administrative and technical tasks. Completing administrative and technical tasks is another effective way to get started. Begin by reading the

proposal guidelines and requirements for the potential funding agency or foundation, or the guidelines issued by your department. Fairly early in the process you should put together a simple outline that lists the key sections of the final document. (This is discussed in Chapter 3.) Think about the optimal length for each section. You will quickly realize that most grant applications are concise. Fifteen single-spaced pages is the maximum for a project description submitted to NSF; many other agencies have similar page limits. Other programs, such as RAPID, EAGER, and dissertation improvement grants offered by NSF, have much shorter page limits. (Refer to NSF reports and web links in the References and Resources section.)

Another important task is to determine your institution's procedures for grant processing. Speak to your institutional grant manager (typically located in a sponsored programs or grants management office) as early as possible. Getting advice from an experienced colleague will also save you time in the long run. Ask questions such as "What paperwork must I complete?" "What signatures do I need?" "Where do I go?" "How much time should I allow?" "What are my institution's rules on budgets, overhead costs, and cost sharing?" "Do I need special permission for anything?" (For example, research that includes use of animal or human subjects involves a special permission process.) If you are writing a dissertation or thesis proposal, check with your department

or the graduate studies research office to determine the process you must follow and the paperwork required, as well as the schedule for submitting it. These seemingly mundane points are critical, for poor planning may result in a scramble to meet due dates or, worse, missed deadlines. Proposals that are improperly formatted or that don't follow the submission guidelines are typically returned without review. All of your hard work will have been for naught.

As you get started is also a good time to assess what types of compliance will be required for your research and what steps you will need to take to ensure compliance. Many areas of research require special compliance, including research that involves human subjects, vertebrate animals, environmental disturbances, flying drones, and classified activities. (Compliance is discussed more in Chapter 18.) In some cases, specialized training, certification, or permission for access may be required and will increase your lead time significantly. Your sponsored programs office can point you toward information on the compliance requirements of your university and your potential funding entity.

It is also beneficial to start thinking now about any supplemental documentation you will need to include with your proposal. Letters of collaboration from individuals or organizations not included in this particular project are helpful supplements or appendixes that avoid leaving reviewers with unanswered questions. These must be negoti-

ated on time. An example of a letter of collaboration would be one that comes from a specialized laboratory where some of your samples will be processed or from a cooperator who is willing to provide samples to you for analysis. Other types of supplemental documents include management plans for your project, information on postdoctoral mentoring, data, and field and logistical plans.

As you collect information for submitting a proposal to your potential funding agency, be sure to learn about the requirements regarding electronic submission. Many institutions have their own deadlines and proposal submission web interfaces that you must use. All granting agencies use electronic submission and processing of grant applications. For example, NSF requires electronic submission through either its FastLane program (www.fastlane.nsf.gov) or through Grants.gov (www.grants.gov). Be sure to check the RFP for any specific guidance on which platform to use. Most other federal grantors also receive applications through Grants.gov, which, according to NSF's Proposal and Award Policies and Procedures Guide (PAPPG), is the primary access point for electronic applications to more than one thousand programs awarding approximately $500 billion annually offered by the twenty-six federal granting agencies. These portals allow a researcher to prepare and upload the proposal in parts—including figures, tables, and budget—and to revise the proposal multiple times before

final submission. For local proposals, such as those submitted to your institution for a dissertation or laboratory equipment purchase, submission may be through informal paper copy or email.

EXERCISE 1.4. Develop the conceptual framework of your research. Conceptualizing your research is the most substantial step in preparing a proposal. Some people work on their ideas for months or years before they begin to write. Others, especially students, pull together their ideas only when they are required to write their research proposal. In our proposal development class, each student spends several weeks working to produce a succinct statement of the overall concept that can be understood by a broad scientific audience. (This process is discussed in Chapters 4–7.) The overall concept statement becomes the foundation for the rest of the proposal. (This is covered in Chapters 8 and 9.)

Know Your Audience

Grant applications are written for a variety of purposes and are submitted to many different types of agencies. Before you begin writing, you should also be aware of the targeted agency's overall mission as it relates to funding research activities. Make sure to consider the fit between your research goals and those of the agency.

Agencies have various reasons for announcing an RFP or establishing a program that will periodically accept proposals. In this book we focus on federal funding agencies, such as NSF, NASA, or NIH, and private corporations and foundations. For the most part, we discuss basic research proposals in which the investigator sets out research questions and goals. Agencies sometimes set the goals, however, and request proposals to address particular objectives, research targets, or initiatives. Accordingly, we separate proposals into two general categories:

1. Basic research proposals, which generally must provide novel insights or methodologies for solving fundamental scientific problems
2. Task-oriented or program-initiated proposals, whose topic or goal of research is specified by an agency, a corporation, or a foundation

There is usually less latitude in determining research topics for task-oriented proposals than for basic research proposals. These proposals are evaluated according to the likelihood that they will succeed in accomplishing the specified task. Reviewers of task-oriented proposals emphasize methods, ability to accomplish the project, credentials, projected outputs, and the cost and time needed to complete the project. These criteria are also important in basic research proposals, but they are not the only criteria.

Both categories of proposals are usually solicited by long-standing or newly announced solicitations, RFPs, Requests for Applications (RFAs), or other announcements of intent. Solicitations have specific language that indicates what types of activities will be funded by the agency. It is essential in the very early stages of your planning to read the solicitation carefully and talk to colleagues who have experience with the particular agency.

Once you have identified a specific program or agency and become familiar with the RFP and other guidelines, you should plan to speak with the program officer at the granting agency who will be evaluating your proposal. Discussions with the program officer and with scientists in the pertinent fields will save you much time and effort and could make the difference between success and failure. Although you may feel intimidated by the prospect of making contact with the program officer, researchers are encouraged to do so (Spires 2012). Remember, the program officer has, in all likelihood, been in your position; most program officers started out as, or still are, active researchers (Wade 2013). Here are some tips to help you plan your conversation with the program officer.

- Send an email to introduce yourself and set up a time for a phone call. Accommodating the program officer's schedule will lead to a more successful outcome than a cold call will (Spires 2012).

- Be sure you have specific questions before you initiate contact.
- Plan to discuss the goals and general format of your project. Ask questions such as "Does my proposed research fit within the mandate of your program?" "Is there a related program that you think would be better suited to evaluate my project?" Avoid open-ended queries such as "What kind of proposals do you fund?"
- Be sure to answer as many of your questions on your own as possible. Don't use your time with the program officer to ask questions that can be answered by the proposal guidelines or by talking with colleagues (Spires 2012).
- Aim to clarify with the program officer whether there are any unwritten requirements for successful grants, such as geographical focus areas or logistical constraints. For example, you may wish to address a question by comparing data from diverse regions around the world, but the agency may be interested only in questions about a particular region. The program officer can explain issues relating to the scope of the program.
- Be sure to ask about spending limits, restrictions on equipment purchases and investigator salaries, and

other financial regulations that may be specific to this grant. (This topic is covered in Chapter 13.)

- Take notes during the conversation.

It is appropriate to ask the program officer about the review process. Find out the general backgrounds of the scientists who will evaluate your application. By knowing your audience, you can anticipate questions and address likely concerns in the proposal. This information is especially critical for proposals that cross disciplinary boundaries. When conducting interdisciplinary research, you will need to address the questions of individuals in each discipline.

Key Points

1. Whether you're developing the overall concept for your project or outlining your timeline and task list, start big. Think in broad terms at the highest level and then work your way down into the details.
2. Get organized early and create a timeline that will allow you to develop your best proposal without too much last-minute rushing to meet your deadline.
3. Make contact with both your sponsored programs office and the program officer at the agency where you'll be submitting your proposal.

Homework

You will not be able to complete all of the assignments for this chapter in a single sitting. We recommend getting a start on each one as soon as possible and revisiting them regularly to continue developing the intended output. Distinguish tasks that can be accomplished in one or two days from longer-term chores.

1. Gather sample proposals from colleagues to critique and use as examples as you develop your own process and style. Spend time reviewing these samples.
2. Familiarize yourself with the funding processes at key agencies and read sample RFPs. Acquire the most recent set of proposal guidelines for any agency to which you might be submitting a proposal.
3. Contact your sponsored programs office and develop a plan for contacting the program officer at the funding agency.
4. Develop a list of administrative tasks; start with higher-level master tasks and add more-detailed subtasks as you go along.
5. Develop a timeline; start with higher-level milestones and refine with intermediate steps as you go along. If

you are responding to an RFP without a deadline, set your own deadline.

6. Begin to identify specific sections required in the final proposal, and list the elements they should contain.

CHAPTER 2

Authorship from Start to Finish

> The best thing you can do to build a collaboration is to do what you agreed to do, when you agreed to do it. A simple rule, but very important.
>
> —Peter Groffman, Advanced Science Research Center, CUNY; and Department of Earth and Environmental Sciences, Brooklyn College

Responsibility for research extends from conception and completion of a proposal to publication and future use of the resulting data. The individuals who accept this responsibility—and the credit for the ideas, methodologies, and eventual results developed in a proposal—are the authors, or investigators, of that proposal. Sometimes authorship is shared, and co-authorship of grant proposals usually leads to co-authorship of the resulting publications. Students and early-career researchers often have questions about authorship, such as:

- "Who are the authors of a proposal?"

- "Do the proposal authors also become the authors of the resulting publications?"
- "Who should be listed as first author?"
- "What is the difference between a principal investigator, a co-principal investigator, and an investigator?"

Because the ramifications of authorship are so important, we discuss it near the start of our proposal development class.

At the proposal stage, authors are referred to as "principal investigators," or PI's. A project can have a single PI or a group of co-PI's. They are the lead individuals involved in the proposal and are responsible for the execution of the work. Also listed on the proposal are other team members with significant roles in the project. They are referred to as "investigators" (I's or co-I's) or as "other personnel," depending on the funding agency. Collaborative proposals often have co-PI's and co-I's from several different institutions. The approach to authorship on collaborative (inter-institutional) proposals is the same as with intra-institutional proposals; however, your sponsored programs office or the funding agency might have additional rules for submitting collaborative proposals.

The success of your proposal, as well as the resulting research and publications, will depend on clearly defining relationships and roles at the start of the project, even before

writing the proposal. There are two essential points to consider about authorship:

- *Discuss expectations*. Before beginning a collaborative proposal, determine the specific expectations for the contributions of each author and collaborator for all phases of proposal development and research implementation. This includes authorship and revision of publications resulting from a research project.
- *Appreciate all that goes into research*. Understand the components of designing, conducting, analyzing, and writing scientific research. Fully acknowledge sources of supporting information, derivative ideas, and collaborators. As this understanding and appreciation develop, appropriate authorship decisions will become clear, and there will be fewer chances for misunderstanding.

In this chapter we will look at each of these points and examine issues of data ownership.

Define Expectations at the Outset

Science advances when researchers share their ideas, provide honest, constructive criticism to their colleagues, and are open to revising their perspective and approach in response to new ideas and critical appraisal. Science is

always collaborative at some level; research requires trust and understanding among associates. Be generous with your feedback to others, and you will benefit as well. Don't let fears of having your ideas taken without credit diminish your relationships with collaborators and colleagues.

You should discuss authorship of possible publications even as you write the proposal. Inherent in such discussions are expectations that the research will be taken seriously, be executed well, and be interesting enough to merit publication. You and your collaborators will probably return to this topic of discussion several times after the research design is complete.

The most effective way to avoid authorship disputes or misunderstandings in a collaboration is to establish, at the start, clear expectations for all members of a project.

Determining the PI and associated responsibilities. Begin by asking, "Who is the first author, or PI, and what are that person's responsibilities?" Every author on a proposal or paper has assumed intellectual, ethical, and fiscal responsibility for the research project. However, the PI takes primary responsibility for the project, just as the first author of a scientific paper usually takes primary responsibility for the overall design and execution of the work and the interpretation of the results. This author often does the greatest amount of work conceptualizing and implementing the project, although

some projects may be conceived by one person and carried out and expanded by another (see Day and Gastel 2006).

Accepted conventions for the order of authors—and, by extension, investigators—vary by field. The PI of a proposal might even become the last author of a publication. Some journals might request information about each author's specific contribution to the work. For certain proposals, the funding agency or review committee mandates the first author and the presence or absence of collaborators. For example, a proposal submitted by a graduate student to a dissertation committee typically carries only the student's name even though the advisor usually has a guiding role in the proposal. A later application to an outside agency may well

"LET'S DO ROCK, PAPER, SCISSORS FOR FIRST AUTHOR."

be co-written by the student and the advisor. Some funding programs (such as NSF dissertation improvement grants) require that the PI on grants be a faculty member at a research institution or an accredited college or university. This policy ensures that applicants have scientific training, experience, and affiliation with an institution that is committed to management of the work; it also directs fiscal and ethical responsibility to a specified individual and place. Proposal solicitations usually include these types of requirements under a section describing eligibility for specific grants.

Determining sources versus collaborators. Shared authorship should be given to joint associations like those between advisors and students, long-standing research collaborators, and co-writers. Co-investigators are usually added to a proposal when their expertise is required for the research. If you have a casual conversation with someone and provide a good idea that the person uses, you should be flattered, and you may be acknowledged, but your suggestion will probably not entitle you to participate in the project. Scientists frequently interact with each other and make suggestions about each other's research; if your suggestions are good, they may even be used frequently, but they do not always lead to collaboration.

Being a co-investigator on a grant application generally implies a long-term contribution to the ideas, design, implementation, and data analysis, as well as to future publi-

cations. Each case should be decided on its own merits, but early discussion of this issue is essential.

Appreciate All That Goes into Research, and Give Credit Where Credit Is Due

To give proper credit and to determine authorship of eventual publications, you must recognize the importance of all contributions to the scientific research. This understanding is also critical for writing a proposal and determining how and when tasks will be performed. Less-experienced researchers may feel that the most important contributions come from those who physically collect the data. But even though data collection is important, participation in the following areas may be even more critical to the outcome of the research, and it could lead to first authorship of eventual papers:

- Identifying research topics and important problems and questions
- Formulating the theoretical foundations of the research
- Designing effective research protocols
- Analyzing samples
- Analyzing data
- Writing the document

If you and your collaborators discuss authorship early, you are more likely to avoid misunderstandings later. The discussion may also help guide decisions about who will do key pieces of the project and about the timeline for project completion, which will facilitate the success of the research effort.

No One Owns Ideas. Right?

Research, by definition, is not about ownership but about increasing and sharing knowledge. Yet we all have assumptions about who gets to use project data and publish the results. Typically, the investigators of a project have sole access to the first use and publication of the data. After the results are published, the data may be used by anyone who properly cites the published work. Virtually all funding agencies have data-sharing policies. Some agencies or programs also require that data be made publicly available within a certain time period, even if the data have not been published. Funding agencies usually require that investigators include a data management plan with their proposals. This plan outlines how investigators will make data and, in some cases, samples available to the public. (The data management plan is discussed more in Chapter 9.)

Protocols and practices regarding ownership of data vary by discipline. Laws regulating intellectual property

rights and patents apply in some areas of science and not others. If you have questions about the ownership of ideas, techniques, or instruments you plan to develop, be sure to contact your institution's sponsored programs or grants management office before you move too far into the project. Difficulties can arise if collaborators have not anticipated what will happen to research and data after a proposed project is completed. It is particularly important to discuss this issue with students, postdoctoral fellows, and other research associates before beginning a collaborative project. The following examples illustrate common situations in which research may be expected to stay within a lab—that is, under a specific laboratory director or PI—even after a primary researcher on a project, such as a graduate student, technician, or research associate, leaves the lab.

Longitudinal studies. Because longitudinal studies follow specific individuals or sites over time, their value grows over time. The initial database often yields additional research opportunities. Examples of longitudinal databases include observation of individuals after exposure to pollutants, drugs, hazards, or other variables; observation of plots of trees as they grow from seedling stage through maturity; repeated analysis of cancer registries; and repeated visits over a long time—perhaps decades—to sample soils or sediments. In most cases, the investigators who designed, arranged to fund, and executed an original study control access to it after the

initial grant period by continuing to maintain the research sites or follow the individuals involved in the study. A student or co-investigator who joins a project with specific objectives for use of the original sites or individuals in the study should not assume that they are guaranteed future access.

Laboratory study systems. In some fields it is common for students and postdoctoral fellows to conduct research on systems—for example, specific genes or gene products—that have been identified, described, and manufactured by previous generations of scientists in the same lab. Scientists training in the laboratory often leave their projects behind when they assume positions elsewhere, where they develop new systems separate from their thesis work.

Technique and instrumentation development. For many scientists, developing new techniques and applying sophisticated instrumentation to novel problems are primary research objectives. Individuals who use these techniques or rely on instrumentation developed and maintained by others cannot assume that they will have future access to and involvement with the instruments or techniques.

We urge you to discuss ownership in advance with colleagues, collaborators, and advisors. Understand the culture of each field with respect to this concept. If you are uncomfortable with the prospects, discuss them with the appropriate people early in the project. Don't assume that you can agree now and change expectations later.

One of us was involved in a large project with a team of five, including graduate students and faculty members. Early in the project we wrote down the area in which each person would assume responsibility for researching, writing, and revising. We even wrote the potential titles of resulting papers and listed the journals in which we intended to publish. Five years later, much of the work had been completed, and most of the papers had been written, with little debate about who would be the lead author on each paper. We ascribe this consensus, in part, to having identified ownership of the different parts of the project early in its development.

Exercises for Thinking about Authorship

The best preparation for thinking about writing proposals and papers is to share opinions about it with your colleagues or advisor. We have an annual seminar with our graduate students on this issue, and it is always thought-provoking and interesting for the participants.

EXERCISE 2.1. Read these scenarios and discuss your expectations for collaboration or eventual authorship.

> *Scenario 1.* You have developed a set of hypotheses to test in a system you know quite well. You present your ideas at an informal department gathering. A colleague tells you about a paper that describes an appropriate testing method for your suggested project. If you use

the method in your eventual design, what should your colleague expect in the way of recognition?

Scenario 2. You have developed a set of hypotheses to test in a system you know quite well. However, the methodology needed for conducting your tests does not exist. Suppose a colleague suggests a way to achieve your goal or offers to develop a method that would meet your needs. If, in your eventual design, you use the method, what type of recognition should you offer? What type of recognition will your colleague expect?

Scenario 3. Finally, consider this scenario, in which a misunderstanding may easily occur. Suppose a number of casual chats held over weeks or months with a particular colleague help you develop ideas on how to test a hypothesis. What if your colleague's perception of how much help you received differs from yours? What should you do?

Key Points

1. It is important to discuss authorship and roles with your collaborators early in the proposal development phase.
2. Defining the expectations of all project collaborators for the duration of the project, including responsibil-

ity for eventual publications, helps to avoid misunderstandings along the way and later.

3. Investigators on the project have first access to the results of the study, such as data or instrument development. However, when a researcher leaves the laboratory in which the study was conducted, the data or instrumentation may stay with the original lab.

Homework

1. Make a list of all the people who will be contributing to your project. If you don't have names but know that you will be supporting a certain number of students, include placeholders for them.
2. From this list, identify the people who should be included as principal investigators as well as those who should be listed as "other personnel."
3. Discuss the assigned roles and responsibilities for writing the proposal with each of the people you have identified as co-PI's.
4. Also from your list, identify the people who may be included as authors on future publications. This will help you to plan your project execution and project budget. For example, you may be planning to hire

postdoctoral researchers or graduate students to work on your project. Although these researchers may not be included as co-PI's, they may well make significant contributions to future publications.

CHAPTER 3

Basic Organization and Effective Communication

> In addition to following the agency's guidelines, successful proposals typically contain sub-headings to make it easier for the reader to follow the logic of the proposal and to find key information.
>
> —Charles E. Dunlap, Research Competitiveness Programs, American Association for the Advancement of Science (AAAS)

Many novice writers find it difficult to decide on organizational structures for their proposals. The number of sections and the disparate types of information that must be included can be overwhelming. Although the key to a good proposal is sound science, efficient organization makes a scientifically convincing project much stronger.

Some funding agencies are flexible in their specifications for proposal format. Others require that sections be presented in a particular sequence. Our recommendations in this chapter are based on the format suggested by the U.S. National Science Foundation's Proposal and Award

Policies and Procedures Guide. The PAPPG, which is free, is updated regularly and is a very useful document for anyone working on a proposal—even if that proposal is not for submission to NSF—because it clearly specifies typical research proposal expectations. Always be sure to use the most up-to-date version of proposal submission guidelines from the funding agency to which you are proposing.

In this chapter, we will give you five key precepts for organizing and communicating your ideas in your proposal. Using the NSF as an example, we will look at how a proposal is evaluated and how you can organize the contents of your proposal to meet agency requirements and keep your readers focused. Finally, we will discuss some common pitfalls in organization and communication.

Five Precepts for Effective Organization and Communication

Effective communication substantially improves your chances of success. If your language is clear, concise, and precise and your document is well organized, your ideas will be better understood, their importance will be more apparent, and the comments of reviewers will be more useful. We propose five precepts for communicating your ideas:

Organize. A well-organized document is easier to follow and comprehend. Use the outline presented in this

chapter and add subsection headings to ensure good flow in your proposal.

Highlight. Highlight your most important points early in your proposal. This directs readers toward the issues that you feel are vital and increases the impact of the proposal. Do not emphasize ideas that are less important to your research, and do not bury critical information.

Funnel. Whenever possible, funnel readers from the broad view, the big picture, to the specifics of your research. Offer readers a road map early in the proposal, and offer signposts in each section to keep readers headed in the direction you wish.

Focus. Focus on the topic at hand; avoid giving information that detracts from or dilutes your message. Funneling and focusing establish for the reviewer that your project is the most effective and logical way to answer the questions you have raised.

Unify. Finally, unify both the voice and the central goals of your project. If your proposal has more than one author, be sure to check for consistency in writing styles and terminology. The best proposals read as if they were written by one person. In addition, you should unify the overall research themes by pointing out how they are linked. (See Chapter 17 for further discussion on the importance of unifying.)

Using these five precepts in proposal writing will help to ensure that you are effectively communicating your ideas and plans to your readers. They apply to more than just proposals. Once you get the hang of approaching your writing with the five precepts in mind, you'll likely find yourself using them for papers and presentations, too. You may even want to print them out and hang them near your desk as a reminder to yourself whenever you are writing.

Considering How a Proposal Will Be Evaluated

How your proposal will be evaluated—whether by a program officer at a federal agency, an ad hoc committee of your peers, or your dissertation committee—should shape its structure and message. Knowing how it will be evaluated will help you to determine how to organize your proposal and what sections to include, as well as what information may or may not be important to your readers. Start by looking at the organizational structure of the program for which you will be submitting your proposal and examining the proposal guidelines of the agency and the specific solicitation. In our example, we consider how NSF is structured and how that leads into the review process. (All the information about NSF, and all quotations, comes from the NSF's published reports and website and is up-to-date to 2017 unless other-

wise indicated. Reports and web links are listed in the References and Resources section at the end of the book.)

The National Science Foundation is an independent federal agency mandated to promote and advance scientific progress in the United States. According to published data, the foundation receives almost fifty thousand proposals annually and authorizes about twelve thousand new awards each year. These numbers indicate that the competition is intense; indeed, in 2016, 24 percent of the submitted proposals were funded. Success rates at NIH are around 20 percent (NIH 2016).

Several types of proposals are submitted to NSF, but we focus here on what are known as "full proposals." These are generally described in the PAPPG as basic research proposals that can be submitted in specific topic areas. To understand how NSF topic areas are defined, it is helpful to understand the organizational structure of NSF. At the highest level, NSF is organized into seven research directorates:

- Biological Sciences
- Computer and Information Science and Engineering
- Engineering
- Geosciences
- Mathematical and Physical Sciences

- Social, Behavioral and Economic Sciences
- Education and Human Resources

These directorates are further broken down into divisions, and each division is separated into multiple programs. For example, within the Directorate for Biological Sciences there are divisions of Biological Infrastructure, Environmental Biology, Integrative Organismal Systems, Molecular and Cellular Biosciences, and Emerging Frontiers. The divisions are subdivided even further. For example, the Division of Environmental Biology has four core programs, or clusters: Ecosystem Science, Evolutionary Processes, Population and Community Ecology, and Systematics and Biodiversity Science. If you follow the organization of all the directorates at NSF down to their divisions and programs, you will quickly realize that there are hundreds of unique programs and thus many funding opportunities.

According to the PAPPG, a proposal "should present the intellectual merit and broader impacts of the proposed project clearly and should be prepared with the care and thoroughness of a paper submitted for publication." Specifically, the full proposal should present:

1. "Objectives and scientific, engineering, or educational significance of the proposed work"
2. "Suitability of the methods to be employed"

3. "Qualifications of the investigator and the grantee organization"
4. "Effect of the activity on the infrastructure of science, engineering, and education"
5. "Amount of funding required"

Note that the PAPPG statement highlights key criteria that reviewers use to evaluate proposals:

- General implications of your research (1)
- The strength of your argument for funding (1 and 5)
- Scientific soundness (1 and 2)
- Fundamental importance (1 and 4)
- Possibility for far-reaching impact (4)
- Investigator qualifications (3)
- Likelihood that the project will advance research efforts in a discipline (1 and 4)

All reviewers for NSF are asked to consider certain questions.

1. "What the proposers want to do"
2. "Why they want to do it"
3. "How they plan to do it"

4. "How they will know if they succeed"

5. "What benefits will accrue if the project is successful"

They are asked to justify their evaluations and recommendations with regard to two specific merit criteria:

> *Merit criterion 1.* What is the *intellectual merit* of the proposed activity? Reviewers are asked to evaluate the potential of the proposed work to "advance knowledge and understanding within its own field or across different fields."
>
> *Merit criterion 2.* What are the *broader impacts* of the proposed activity? Reviewers are asked to evaluate the potential of the proposed activity to "benefit society and contribute to the achievement of specific, desired societal outcomes."

For both criteria, the PAPPG lists points that reviewers must consider:

- Whether and to what extent the proposed activities "suggest and explore creative, original, or potentially transformative concepts"
- Whether the plan for carrying out the proposed activities "is well reasoned, well organized, and based on a sound rationale"
- Whether the plan "incorporate[s] a mechanism to assess success"

- Whether the PI(s), team, or organization is qualified to conduct the work
- Whether the resources available to the PI(s) to carry out the work are adequate

As you can see, knowing where your funding program fits within its larger agency or organization and knowing the core requirements and guidelines for submitting proposals are both very important. Don't forget to also look at any special requirements set forth in the specific solicitation or by the specific program for which you are submitting a proposal.

Organizing a Proposal for a Federal Agency

The sections commonly found in the main body of most proposals, including those for NSF, are outlined below. Detailed descriptions of each are found in upcoming chapters, as noted in parentheses. Some writers do not supply all these sections; others supply more.

I. Cover sheet
II. Project summary or abstract (Chapter 6)
III. Table of contents
IV. Project description (the main body of the proposal; NSF does not specify its placement)
    A. Results from prior agency support (Chapter 8)
    B. Statement of the problem and its significance (Chapter 4)

C. Introduction and background (Chapter 8)
- Relevant literature review
- Preliminary data
- Conceptual, empirical, or theoretical model
- Justification of approach or novel methods

D. Research plan (Chapter 9)
- Overview of research design
- Objectives or specific aims, hypotheses, and methods (Chapters 7 and 9)
- Analysis and expected results (Chapters 9 and 10)
- Timetable (Chapter 11)

E. Broader impacts (Chapters 6 and 10)

V. References cited (Chapter 12)

VI. Budget and budget justification (Chapter 13)

When submitting proposals to federal agencies, you'll also need to submit myriad other documents, including biographical sketches (or curricula vitae) of the principal investigators, descriptions of other current and pending support to you and your co-PI's, separate documentation on the facilities, equipment, and resources to be used, and any additional supplemental documentation specified in the RFP (such as a data management plan, a project management plan, a postdoctoral mentoring plan, letters of collaboration, or field and logistical requirements). You may also want to submit suggested names of reviewers. These additional documents are not included in the outline above (though some are discussed in more detail later), for there are generally standard or fairly straightforward formats to follow for creating these supplemental parts of the proposal.

Organizations may have different specific requirements, but most include roughly the same elements. They may emphasize more or less detail or different sections, such as experimental protocol. A few agencies require additional components, such as quality assurance information, special permits, or cooperative agreements. You will need to obtain information about these additional components from the program directors.

Some programs require particular headings and a fixed order of presentation. For NSF, the overall sequence is prescribed in the PAPPG, but within the body of the proposal the writer has a great deal of latitude in regard to content, headings, and placement of sections. When you write your proposal, creating subsections in your project description will help you achieve the five precepts for effective communication listed at the beginning of this chapter (*organize, highlight, funnel, focus,* and *unify*). For the resubmission of a proposal, many programs also suggest or require a "resubmission response" in the main body of the proposal. (For more on resubmissions, see Chapter 15.)

Common Pitfalls

Perhaps the most common conceptual pitfalls are the failure to establish the general significance of your work and the failure to link it logically to your proposed project. Other typical errors are to devote too much text to complex

details or to your past accomplishments. Unless these are pertinent to your study, you could lose the attention of reviewers. Other widespread weaknesses include the failure to construct testable hypotheses or identifiable aims, the construction of too many hypotheses or goals, bad analytical or statistical methods, poor experimental design, weak questions, inappropriate tests to accompany a good big-picture question, too ambitious a project for the time and money requested, and inadequate skills or credentials for the task proposed. Finally, there are several procedural pitfalls to be avoided at all costs. Most are obvious, but they can be critical. For example, make sure to maintain a good impression by presenting a document free of typographical errors, erroneous references, and incorrect or inconsistent numbers. Follow all page-length guidelines. Present a pleasant-looking document that is legible, logical, and reader friendly. As with all other steps in the writing process, evaluating other proposals and looking at your own project with organization, communication, and pitfalls in mind is of great benefit.

Key Points

1. Most proposals contain six basic sections: cover sheet, summary, table of contents, project description, references, and budget. Additional sections, as defined by the funding entity, are common, and it is important to

ensure that all required sections are included in your final proposal submission.

2. Five precepts—*organize, highlight, funnel, focus,* and *unify*—will help you achieve good organization and effective communication, both of which are key to a successful proposal.
3. Be aware of common pitfalls and avoid them.

Homework

1. Create a full outline for your proposal by expanding and organizing the list of sections you identified as part of the homework for Chapter 1. The outline should include all sections required by your funding entity.
2. Develop subsections within your project description section to organize the content and ideas of your proposal.

CHAPTER 4

Developing Your Conceptual Framework and Significance Section

> I find concept papers to be extremely helpful and keep several on hand so that as RFPs come up, I can see if my ideas align with the RFP. Sometimes the nature of the beast is that I have to think outside of my primary area of interest to pursue funding.
>
> —Lacy Cleveland, Mathematics and Science Teaching Institute, University of Northern Colorado

Scientists agree that time spent developing a proposal's significance, objectives, and hypotheses, aims, or questions is time well spent. Many researchers find it useful to develop and keep on file short concept papers (one to two pages long) that outline these key components of their research ideas. When solicitations are announced, a concept paper can help you identify whether or not your proposal might be a good fit.

Proposal reviewers judge scientific proposals based on their perceived significance. This is true whether you are writing for a federal agency such as NSF or NASA, a private

organization such as the Keck Foundation, a local conservation society, or a dissertation committee. Everyone who funds or supervises research inevitably asks what makes the proposed research significant. If you cannot answer this question, stop writing and keep thinking.

In this chapter, we offer simple guidelines for writing a compelling significance statement or larger significance section and placing it strategically in your proposal. Depending on the breadth of your overall goals and the length of your proposal, your project's significance may be conveyed in either a short statement (a single paragraph consisting of a few sentences) or in an entire section with multiple paragraphs. For simplicity, we use the word "section" to mean either.

Developing Your Significance Section

Persuasive questions are essential for successful proposals. In fact, they are the first of the four cornerstones underlying good research. (We'll discuss the others in later chapters.)

- Persuasive questions
- Best and most appropriate methods or approaches
- Appropriate analysis and application of results
- Synthesis and timely dissemination of results

A significance section usually features the questions your study will address along with the justification for those questions. Many scientists feel that this is the most important piece of a research proposal. A well-written significance section highlights the fundamental value of the proposed research, so many authors start the project description unit with a significance section. (Revisit Chapter 3 for the components of the project description.) The significance section should be linked to the specific objectives, aims, questions, or hypotheses of your study, which should follow close behind the significance section in the proposal. (These features are discussed in Chapter 7.) The reviewer must find that the logic in the significance section is sound, that the ideas are exciting, and that the scope is reasonable within the time and budget you propose.

To refine your thinking on the significance of your research, step outside your own discipline and immediate needs and take a broad and long-term view of your research. Think about how you might begin your elevator speech to a stranger. In this case an elevator speech would be a brief and persuasive description of your research and its value—told in less than thirty seconds. This perspective is essential for building a valuable and wide-reaching set of hypotheses. The goal is to end up with a pithy and accurate statement of your project's significance before you proceed further. While writing or evaluating the significance section of your proposal, we suggest that you take these steps.

- Look at the project from both broad and narrow disciplinary viewpoints.
- Ask what scientists both inside and outside the field would perceive as the greatest contribution of the research.
- Consider both empirical and theoretical contributions that may result from the study.
- Identify and contrast basic and applied uses of the data.
- Ask how you most expect and hope others will use your research.
- Compare contributions of the project that are likely to be important one year and then ten years after the completion of the project. Remember that the significance of a project changes with time and technology.
- Be your own best critic and ask how an impartial reader might challenge the claims that you have made.

Preparing to Write the Significance Section

To help hone your skills, we suggest that you critique the significance sections of other proposals. In the classroom, we use a supply of proposals given to us by their authors. You can do this with the proposals you acquired as part of

"SOME DAYS IT TAKES EVERY SCREEN TO SEE THE BIG PICTURE."

your homework for Chapter 1. Evaluate the effectiveness of the significance sections based on content, perceived importance of the questions, placement in the proposal, basic writing skills, and style. This activity is valuable at any time in the development of a proposal.

Here are four excerpts from significance sections for you to consider. Are they cogent? Are you engaged? Do they successfully cover the points listed above? Have the authors avoided common writing and style pitfalls?

Example 1. *Field Measurements of Phytochelatins in Crops and Ecosystems Contaminated by Metals*

Understanding how metal pollutants affect crops and forests is obviously of great importance to U.S. agriculture. Much research is aimed at elucidating the mechanisms

of plant-metal interactions, including the induction of phytochelatins.

Source: F. M. M. Morel

Example 2. *The Evolution of Mate Choice in Damselflies*

The broad objectives of our work are to explore the consequences of various speciation mechanisms to the assembly of real ecological communities over evolutionary time. . . . By understanding the role of sexual selection in generating new species, this system could become an exemplar for how many ecologically similar species can be rapidly introduced into an ecological system, and thus be a model for exploring how niche- and drift-based mechanisms interact to shape the assembly and dynamics of real communities on a continental scale.

Source: M. A. McPeek and H. Farid

Example 3. *Understanding Hydraulic Conductivity in Aquifers from Above-Ground Measurements*

Understanding hydraulic conductivity of a variety of aquifers has global importance and cannot be undervalued given the enormity of environmental problems related to contamination of aquifers. Our proposed technique, if successful, has the potential to revolutionize the way that groundwater studies are conducted. It may also greatly affect the rates of species extinction, climate change, and frequency of El Niño events.

Source: A fictional proposal

Example 4. *Understanding the Origin and Asymmetry of Life*

This proposal addresses some of the key questions that must be answered if we are to truly understand life's

origins here or anywhere else. It is designed to fully integrate our present and near-future observational and experimental knowledge with cutting-edge computer simulation techniques. It will serve as a springboard to future NASA missions.

Source: M. Gleiser

Examples 2 and 4 do the best job of incorporating many of the points presented above. They also engage the reader. The other two examples fall short. Example 1 fails to identify the contributions that will be made by the study. Some of the claims made in Example 3 seem grandiose and unsupported; reviewers are likely to doubt their validity.

Now examine a longer example. Consider the relative weight given to the big picture and its link to the aims of the study. Is this approach effective?

Example 5. *Testing for Cascading Effects of Habitat Fragmentation*

The results of this research will lead to a much richer understanding of human effects on the coastal sage scrub ecosystem. The proposed research capitalizes on the ongoing research of the investigators to generate a synthetic picture of ecosystem dynamics. It will also generate patterns and mechanistic hypotheses that will inform manipulative experiments that the investigators will describe in a forthcoming proposal to NSF. Furthermore, this research will be done in urban nature reserves in a region that has been highlighted for its importance as a test case for resolving human-nature conflicts in urban settings (reference

> given here). The proposed research will provide a diverse array of data that will lead to an in-depth mechanistic understanding that will inform reserve management in this region. The research also addresses fundamental ecological questions of the importance of top-down and bottom-up limitation and regulation of ecosystems (reference given here). These results will be directly communicated to reserve managers as well as to a wider scientific community through consultation with managers, participation in local and national meetings, publications in national and international journals, teaching undergraduate and graduate courses in conservation biology, and the participation of undergraduates, graduate students, and postdocs in the research.
>
> *Source:* D. Bolger and colleagues (modified)

This longer example incorporates all of the points that should be considered when writing a significance section.

Crafting the Significance Section

An effective, engaging significance section motivates the reader to give your proposal a thorough appraisal. It also establishes the framework for the rest of the study. The overall goals and significance should be tied to the information in the background section and lead the reviewer directly to the objectives and hypotheses or to specific research questions. If the significance section is not consistent with the other sections, your proposal will not be persuasive.

A formulaic approach is rarely wise, but we agree with the widely held belief that an effective significance section begins with the big picture motivating your work, elaborates on the scientific context for your study, describes briefly your own research plans, and restates the overall goals and expected results. Here are several tips for producing your significance section, compiled from our reviews of many excellent proposals.

- *Feature the significance section at the start.* This allows you to set the tone for the entire proposal and generate early enthusiasm for your work. Some people place the significance section at the end of the proposal, but we find that this is much less effective. By that point most reviewers will have already formed a firm opinion of the study.
- *Keep the section short.* Don't dilute your message with detail, but be sure to elaborate beyond the project summary. (For more about the project summary, see Chapter 6.) For an NSF-type proposal, one to two pages will generally suffice; many authors keep the statement or section to under a single page to save space. For other projects, such as a thesis proposal, it could be much shorter.
- *Funnel the reader.* Take the reader from your broadest goals to your specific aims. The more effective your

funnel, the clearer the section will be. If you can write a statement in which your research appears to be the most logical and innovative approach to answering the question raised in the first or second sentence, you will have accomplished a great deal.

- *Explain the value of your work.* It is essential that you explain the value of your research questions in a manner that is accessible and convincing to scientists both in and out of your immediate discipline. Perhaps you have identified a glaring gap in knowledge. If so, explain what information is missing and describe how finding that information may lead to other important research. Maybe you plan to work on a process that has been identified in one system but not tested in other systems. You must convince the reader that applying the process and associated ideas to another system is important in some fundamental way. After reviewing this section, the reader should understand how the successful completion of your work will advance the state of science in your field.

- *Link with other fields.* Successful research usually has significance beyond its immediate domain. Briefly explain the implications of your work for other fields and how it can be applied in those fields. This makes your work more appealing, and it emphasizes that your

study has breadth. It also provides a chance for you to identify and describe the broader societal impacts of your research.

- *Don't go overboard.* One important note of caution: be sure not to overreach. Reviewers become annoyed if the claims for significance are out of proportion to the specifics of the research.
- *Experiment with names for this section.* Different titles are commonly used. Some are more forceful than others, depending on the type and objectives of the proposal. Here are some examples from successful proposals. Which do you prefer?
  - Overall Objectives
  - Overview and Significance
  - Motivation and Overview
  - Significance and Project Objectives
  - Statement of the Problem

You can accomplish your task in a variety of ways. When composing the significance section, people often go back and forth between significance, objectives, and methods. We usually first write a rough draft of the significance section, develop the objectives and hypotheses, consider the methods, and then reconsider and rewrite the significance

section. When writing this section, remind yourself of some often-encountered pitfalls: language that is too vague, use of overblown or naive statements of significance, repetition of other sections without additional detail, and confusing or jargon-heavy language that fails to engage the reader. As we stated earlier, it is usually most effective to delay writing until you have read a number of proposals in your discipline and completed the thinking for this section.

Exercises for Developing Your Significance Section

The following exercises should help you conceptualize and articulate your research proposal before you begin to write. View these drills as the building blocks for writing the entire proposal, and follow the five precepts for effective communication: *organize, highlight, funnel, focus,* and *unify.*

EXERCISE 4.1. Prepare a one- to two-page outline (or concept paper) or a ten- to fifteen-minute oral presentation of the conceptual framework for your proposal. To help hone your significance section, challenge yourself to present the conceptual framework without reference to the specific system (e.g., biochemical process, species, habitat) you might be working in. For example, suppose you plan to investigate synergistic effects of exposure to toxic metals on reproduction and growth of oysters in estuaries off the Maine coast.

For this exercise, distill the key conceptual points of your proposal: those ideas that are of importance beyond oysters, the specific metals you'll study, and estuaries in Maine. A possible focus is understanding synergisms among contaminants that occur in combination. The point of departure for paper or presentation could be the need to tease apart mechanisms of interactions among contaminants in order to devise remediation strategies.

This activity forces you to articulate your general research question in broad terms and to relate your study to the theoretical and empirical research that precedes it—in essence, it asks you to describe the significance of your work. If you must use a system to illustrate aspects of the discussion, do not use the system you intend to study.

EXERCISE 4.2. Distill your previous paper or presentation down to a brief written document or five- to ten-minute oral presentation of the significance and broad objectives of your research. This time you can refer to the specific system, cells, or organisms that you actually plan to study. When you can do this effectively, you are probably ready to write a project summary and a brief yet pointed introductory significance statement for your proposal.

EXERCISE 4.3. Now take your concept paper or presentation a step further and prepare a brief written document or ten- to fifteen-minute presentation of the conceptual

framework for your research project, focusing on the underlying quantitative, theoretical, and functional relations. You should be able to do this by expanding your work from EXERCISES 4.1 and 4.2. As in those exercises, emphasize the relation between your study and the theoretical and empirical research preceding it. It can be particularly effective to include graphical presentation—a model or series of models—in your proposal to identify the key relations among processes. (For more about using models, see Chapter 8). Develop a model of the conceptual or quantitative relationships you have identified. Successful completion of this exercise will produce a piece you can use in the introduction to justify your study.

EXERCISE 4.4. Identify a system (e.g., biochemical process, species, habitat) that is analogous to the one you plan to study. Prepare another one-page summary or give a five-minute oral presentation on the significance and broad objectives of your research, this time structured entirely around the comparable system. This exercise forces you to consider the relations between significance and specific objectives more precisely, because sometimes objectives may not be as generally applicable as you believe. This may make you reevaluate your objectives with respect to your chosen system of study.

Key Points

1. A well-written significance statement or section establishes the framework of your research and convinces a reviewer of its importance.
2. Time spent thinking about articulating the significance of your proposed research is time well spent. Knowing and articulating the fundamental value of your proposed research as it fits within a big picture will help you to identify and relate it to more funding opportunities.
3. An effective significance section begins with the big picture and then funnels the reader through your hypotheses to the goals or specific aims of your research.

Homework

1. If you have completed the exercises in this chapter, you should have a nearly complete significance section for your proposal. Go ahead and put any finishing touches on it.
2. After you have written your significance section, ask friends and colleagues to evaluate it for the five precepts: *organize, highlight, funnel, focus,* and *unify.* Ask

if you have clearly addressed the importance of your work from both a broad and a narrow perspective.

3. Edit your significance section. Keep in mind the essential points to cover and the pitfalls to avoid. If you have a solid, persuasive significance section, you are well on the way to completing a successful proposal.

CHAPTER 5

A Title May Be More Important Than You Think

> As a one-sentence description of your proposal, your title will be seen by many people, both inside and outside of your research field. So it is important to make it both understandable and interesting while describing the main objectives of your work.
>
> —Patricia Brennan, Biological Sciences, Mount Holyoke College

Titles are often composed at the last minute and typically receive less thought than the rest of the proposal. But the title introduces your reader to the framework and perspective of the document. An effective title will capture that reader's attention and signal the focus of your work. The role of the title can be significant during the evaluation process, in which a review committee may collectively assess up to two hundred proposals. For example, members of a review committee may start by reading the applications with the most intriguing titles. In group discussions, the proposal may be referred to or remembered by a fragment of the title.

Your project title and project summary (discussed in Chapter 6) are the two most widely distributed and viewed components of your proposal. Various interested people beyond your program officer and peer reviewers can access this summary online. This group may include other researchers, public officials, and the media. Because of this possible exposure, you should be able to write a succinct and unambiguous title that captures the most important features of your work. Once you can do that, your proposal writing will also become stronger and more focused.

This chapter will help you to identify the components of a good title and develop your own effective titles.

Components of an Effective Title

Reviewers often say that they can tell new proposal writers by the titles they select because the titles tend to be wordy and either too specific or overblown. If the title is too descriptive, it may convey an impression that your work is narrow. If the title is too broad, the work may appear unfocused or unachievable. An effective title accurately represents the content and scope of the proposal. Here are some guidelines for writing an effective title.

- Present your title in clear, concise phrasing. Eight to twelve words should be sufficient.

- Avoid jargon and overblown language.
- Be aware that buzzwords can attract some readers but alienate others.
- Use professional language to convey the serious nature of your work. Avoid using wording that is humorous or informal.

By applying these concepts early when developing your own title, you will be well on your way to successfully achieving an effective title for your proposal.

Recognizing Effective Titles

Titles come in several forms: questions, descriptions, and statements. Each form works well in specific situations. Consider this title: "Bedrock Influence on Soil Chemistry in Western Vermont." This descriptive title gives the reader a fairly good idea of the general topic but does not give any details on the system being studied or the questions being asked. "The Influence of Limestone on Base Saturation in Soils of the Lake Champlain Valley" is more specific, but its importance may not be immediately clear to nonspecialists. Both titles are more informative than "The Relationship Between Soils and Parent Material." Which of the first two titles is more desirable may depend on the content of the proposal, the agency or program to which it is being sub-

mitted, and the type of reviewers who are likely to read the proposal—specialists or generalists.

Below are some titles of successful proposals, modified slightly. Notice that all of these titles encompass the focus of the study and employ the key concepts of an effective title.

1. "Analysis of Pesticide Transport Pathways and Degradation in Natural Wetlands"
2. "Human Modification of Landscape Function in New England and Florida"
3. "Predicting the Response of Terrestrial Ecosystems to Elevated CO_2 and Climatic Change"
4. "Thermal Conductivity in Oceanic Waters: Internal and External Factors"
5. "Patterns and Processes of Geomorphic and Hydraulic Adjustments During Stream Channel Recovery"
6. "Mercury Flux Estimates from Sites to Regions: Scaling-Up Across the Northern Hemisphere"
7. "Quasi-Lagrangian Measurements of Polar Stratospheric Cloud Particle Development from Long-duration Balloon Platforms"
8. "Effects of Plasma Ionization on the Nonlinear Dynamics of Emission Spectrophotometers"

9. "Reconciling Molecular and Fossil Evidence on the Age of Angiosperms"
10. "Genetics, Mechanism, and Regulation of Protein Synthesis in *G. hypothetica*"

Even if these titles don't pertain to your specific discipline, you likely understood the intent of each one as you read it. Several of the examples provide specific details on what is to be done, where it is to be done, or how it is to be done. For example, you may not be familiar with the term "quasi-lagrangian" in number 7, but the title tells us that the authors intend to measure cloud particle development (what) in polar stratospheric clouds (where) using balloons (how). Imagine yourself as a reviewer having to review all of these proposals for a panel. Which one would you want to read first based on the title?

Exercises for Writing Effective Titles

Practice is the best way to learn how to write a title. To prepare for writing your own good and effective proposal title, we recommend these exercises.

EXERCISE 5.1. Evaluate and modify existing titles. The titles listed below represent the variety reviewers see in proposals. Some are modified from published titles. Remember, evaluations are not necessarily conducted by specialists in the

same field as the author of the proposal, so titles that can be understood only by a scientist in a particular discipline may not be very effective. Most of these titles can be improved. As you read through the list, consider these questions:

- Is the title understandable?
- Can you easily determine the content and scope of the proposal based on the title?
- Would a few word changes or a different approach make the title more interesting or effective to a non-specialist in this discipline?

1. "Models of Impulsive Behavior in Mice"
2. "Temperature and Moisture: Controls on Global Carbon Cycles"
3. "Mathematical Modeling of Non-Linear Systems"
4. "Nutrient Cycling in Freshwater Ponds: The Role of Two Fish Species and Three Algae Species in Four Lakes"
5. "Basic Research for the Future: Are There Enough Resources to Support the Human Population?"
6. "Erosion in Streams—Slip-Sliding Away?"
7. "Socioeconomic and Environmental Drivers of Infectious Diseases in a Warmer World"

8. "Infrastructure for Studies of Planetary Formation Using the NASA Telescope Facility"
9. "Acidic Permian Lakes: Understanding the Geochemistry of Ancient Acid Systems"
10. "Trade Policy, Child Labor, and Schooling in South Africa and Lesotho"

EXERCISE 5.2. Construct titles from existing project summaries. Using some of the sample proposals you've been critiquing, evaluate both the summaries (or abstracts) and the titles. Do the titles capture your attention? Do they encapsulate the material outlined in the abstract?

You can also practice writing your own titles based on the summaries. Below are example summaries from two funded proposals. Try to write a good title for each. In our class, students drafted titles that were very close to the originals, a testament to the clarity of these summaries. The original titles are listed after the examples.

Example 1

The objective of the proposed research is to experimentally investigate the effects of temporal variation in resource supply on the outcome and dynamics of competition between consumers. The proposed research would use planktonic rotifers (small, multicellular zooplankton) as model systems. Experiments would test the predictions that temporal variation in resource supply changes competitive outcome, slows the rate of competitive exclusion,

and allows competing species to coexist. These experiments would go beyond existing experimental studies by combining the following aspects: (1) using multicellular organisms instead of microbes, (2) using a temporal pattern of resource supply that is more realistic than that used in previous experiments, (3) measuring the effect of temporal variation in resource supply on the threshold resource concentration for positive population growth, and (4) predicting changes in competitive outcome, dynamics, and species diversity at different scales of temporal variation.

Source: K. L. Kirk

Example 2

Overpumping of California's Salinas River Valley aquifers has prompted sea water intrusion, adversely affecting groundwater quality. Consequently, the sustainability of Monterey County agriculture is jeopardized. Growers recognize that the solution to preventing further intrusion lies in regulation of the aquifer, but they differ in their commitment to accepting groundwater upper pumping limits or pumping taxes. In order to motivate grower effort to manage the groundwater resources more effectively, the effect of one grower's pumping on the water quality and quantity of all other growers should be quantified. Because sea water intrudes into the aquifer through diffusion, growers who pump closer to the intruded area cause more damage than those who pump at the other end of the aquifer, given equal rates of pumping across growers. This suggests that a policy that varies by region would be more effective than a basin-wide policy. We will simulate present conditions in the aquifer as well as impacts of policy alternatives through

the use of a Geographical Information System (GIS) computer program.

Source: D. D. Parker

The actual titles for these two summaries are:

1. "Resource Competition Between Rotifers in a Variable Environment"
2. "Spatially Efficient Management of a Sea Water–Intruded Aquifer"

Feedback from friends and colleagues is extremely useful. As you develop your own proposal title, we recommend sharing it with your collaborators and other colleagues. Group discussion of your title will likely lead to changes, sometimes quite radical, and your title will become more precise and focused. If you find this difficult, it may indicate less certainty about the direction of your work, so getting feedback can be helpful as a diagnostic exercise. Another helpful approach is to ask yourself how you would want people to refer to your proposed project.

Key Points

1. The role of the title can be significant during the evaluation process, where members of a review committee might start by reading the proposals with the

most intriguing titles and then also use the title, or a fragment of it, when referring to your proposal in discussions.

2. An effective title accurately represents the content of the proposal and is presented in a clear, concise, and meaningful manner to establish focus and perspective. It also avoids jargon, overstatements, buzzwords, and humor.

3. Effective titles come in several forms—questions, descriptions, or statements. The most desirable form for a proposal depends on the specific situation, the content of the proposal, the program to which it is being submitted, and the type of reviewers who are likely to read the proposal—specialists or generalists.

Homework

1. Write and critique your own title. Construct an eight- to twelve-word description of your project and then, if absolutely necessary, expand it slightly to make it clearer.

2. Now try a number of variations on the title you just constructed, experimenting with the various forms listed in this chapter.

3. Reread the lists of titles presented in this chapter or the titles you've found on your own. As you read these titles, consider possibilities for refining your own.
4. Finally, ask yourself how your title can be clarified, shortened, and made more precise. This would also be a good time to share it for group discussion and input and rework it accordingly.

CHAPTER 6

The Project Summary Guides the Reader

> I think some proposals fall down when the Project Summary fails to tell the reader what you are going to do to address the project goals. If you finish reading the proposal summary and can't visualize how the project will proceed if funded, this component of the proposal has failed.
>
> —Robert L. Hawley, Earth Sciences, Dartmouth College

The project summary is the first, and usually the shortest, section in a proposal. This is where you frame the goals and scope of your study, briefly describe your methods, and present your hypotheses and expected results or outputs. The project summary (also called the "abstract," depending on the funding entity) is the initial description of the project seen by program directors and reviewers. A convincing and exciting summary captures the reader's attention and interest, and it establishes a strong tone for your entire document. Your project summary should also set up proper expectations, so you must be careful to avoid misleading your

readers into thinking that the proposal addresses anything other than the actual research topic.

What a challenge—to be clear, concise, accurate, and exciting, all in a small amount of space. In this chapter, we give you the tools to meet that challenge. We look at the function of the project summary and its effective elements. We also examine the two-paragraph model and some sample project summaries. Then we offer some exercises to prepare you to write your own project summary.

The Function of a Project Summary

The project summary is read and reread more than any other section of the proposal and serves several vital functions. NIH (2017) provides one of the most concise descriptions of the project summary's function: "The project summary is meant to serve as a succinct and accurate description of the proposed work when separated from the application." Program directors frequently rely on the summary when choosing ad hoc reviewers. When assessing your proposal, reviewers will use the summary as a guide to the main document. Their impressions of the summary are critical. Summaries also are used later to remind evaluators of the key elements in your design and of your expected outputs. This function is particularly important for proposals

that are evaluated formally; the summary may be referred to repeatedly during review panel discussions.

Agencies expect scientists to write the summary in a way that a scientifically literate lay audience can understand. Thus, it is worth taking the time to write this brief but important section in a way that will make your proposal topic more understandable for nonspecialists and even the general public. For an NSF proposal, the PAPPG states that the project summary should be "written in the third person, informative to other persons working in the same or related fields, and, insofar as possible, understandable to a scientifically or technically literate lay reader." (Again, information and quotes come from the NSF website and online PAPPG, up-to-date as of 2017.)

The project summaries, or abstracts, of successful proposals funded by federal agencies are published online. Each posted summary serves as a permanent record and description of the proposed work and is searchable by the public. The project directories are accessed by various interested people, including other researchers looking to confirm that their ideas are original prior to submitting their proposals, and by public officials and the media gathering statistics on the types of research funded by an agency. The project summary of a thesis or dissertation proposal is also likely to gain public exposure; the researcher's lab, department, or college may use the project summary to advertise current research.

The Format of a Project Summary

Every agency requires a slightly different format for the section of the document where the proposed research is summarized. However, the goals for the section are generally similar. Before writing your summary, it is a good idea to check out a few sample summaries on the funding agency's website and ask friends and colleagues for copies of summaries they have written. Be aware of the conventions in your field. Also be sure to obtain precise rules and specifications for required elements, including page or character limitations. Length limits vary, but they rarely exceed a single-spaced page. For example, NSF requires that the project summary be less than a single page and include an overview and statements on intellectual merit and broader impacts. NASA's requirements for content are less specific, but the project summary, or abstract, must be less than four thousand characters long and should not contain any special formatting (NASA 2017). NIH also uses the terms "project summary" or "abstract" and requires it to be less than thirty lines of text long (NIH 2017).

Elements of Effective Project Summaries

There is no single template for an effective project summary. Many of the most compelling summaries start with

a broad statement of purpose and then funnel the reader to the specifics of the proposed work. Some authors draft the summary first and then use it as an outline for the grant application, but most write it after the rest of the proposal is completed. The essential feature is that the summary must accurately encapsulate the most important elements of your project.

Our discussion centers on a model suitable for NSF basic research proposals in which the initial section is termed "Project Summary" and contains three components:

1. Overview
2. Statement on intellectual merit
3. Statement on broader impacts

The components of this approach are generally applicable to most other required formats for project summaries or proposal abstracts. However, it is important to include the specific components required by the agency to which you are submitting. For example, an NIH project summary should include these two basic components (NIH 2017):

1. The broad long-term objectives and specific aims, with reference to the health relatedness of the project
2. A concise description of the research design and methods

The description of the project summary in the NSF's PAPPG reads:

> The overview includes a description of the activity that would result if the proposal were funded and a statement of [the] objectives and [the] methods to be employed. The statement on intellectual merit should describe the potential of the proposed activity to advance knowledge. The statement on broader impacts should describe the potential of the proposed activity to benefit society and contribute to the achievement of specific, desired societal outcomes. . . . [The overview] should not be an abstract of the proposal.

This general description distinguishes a proposal summary from a manuscript abstract. In a proposal for a research project, you report what you plan to do and stress why your work will be influential. It should not be about what you have already done and why that work is important. Rather, place your emphasis on the consequential outputs, intellectual merit, and broader impacts that will result from the proposed activity. Both "intellectual merit" and "broader impacts" are explicitly stated as review criteria that must be included in the project summary of NSF proposals; the National Science Board establishes these criteria. NSF also requires that the project description (the main part of the proposal) includes a separate section titled "Broader Impacts" where you will expand on the statement in the project summary.

You should highlight the expected outputs and the novel aspects or particular qualifications that explain why your proposal should be selected over others seeking to achieve similar goals. While results are not included in the summary, you may refer to your previous research to make a point or to establish your ability to accomplish the proposed task. Panelists judge many proposals in a short, intense time period, and you can make your work stand out by providing concise, precise, memorable sentences and phrases in the project summary or goals section. Remember that whatever you write in the summary will be used to highlight major aspects of your study, so be sure to state exactly what you mean.

"THE PROJECT SUMMARY WAS ALL BLING. THE PROPOSAL, BLAH."

The Two-Paragraph Project Summary

In your summary, you have just a few sentences in which to direct the reader from the most general and broad significance of your proposed research to its specific details. A number of styles and formats can be successful. Some summaries begin with a bold statement: "The proposed work will test the hypothesis that . . ." Others employ a more gradual development of ideas or build chronologically from early views to the current state of the field. The second style is logical, but it may fail to capture the reader's interest at the start because it is less effective at highlighting important points.

We encourage you to begin by writing a two-paragraph summary. Use the first paragraph to introduce the problem and describe the work; this equates with the overview of an NSF proposal. Then, in the second paragraph, emphasize the potential outcome and significance. Include the intellectual merit and broader impacts in the second paragraph or use additional paragraphs if these topics should be separately identified, as for an NSF proposal. Below are some specific recommendations for each paragraph.

Paragraph 1

- Develop the broadest context for the research in the first one or two sentences. This is where you convey the significance of your work as it relates to the

world. Again, think about how you might begin your elevator speech to a stranger; the same factors can be used here.

- State your research questions as testable hypotheses or, where appropriate, as objectives. Never propose untestable hypotheses, or questions or goals that cannot be met with the proposed research.
- Identify gaps in current knowledge and state how your research will fill those gaps or lead the field forward. Establish the overall importance or relevance of your work. This tactic will also help to justify funding your study relative to other well-conceived studies.
- If appropriate, include preliminary results of your own work; these make further work compelling and establish your credibility. however, be careful not to give the impression that most of the proposed work has already been done.
- In the last few sentences of the paragraph, give a detailed, succinct description of the actual work that you will do.

Paragraph 2

- Briefly summarize or describe techniques, study sites, instruments, collaborations, and, if appropriate, the

taxonomic names of study organisms (this description may be in the first or second paragraph).

- Discuss the projected results or output from your proposed study.
- State how your work will advance your area of study; perhaps include a phrase or sentence on the implications of your work for other fields or issues. For NSF proposals, this would serve as the "intellectual merit" statement and be separated into its own paragraph. Be sure you are not making any statements that cannot be supported by your work.
- Specify the broader significance of the work, including how your proposal will advance discovery and understanding while promoting teaching, training, and learning or providing other broad societal benefits. For NSF proposals, this statement should be clearly identified as the "broader impacts" section and would be separated into its own paragraph.

The following project summary uses the two-paragraph model to provide context for a study. Testable hypotheses are stated clearly, and the broader value of the study is stressed. Note that the NSF-required components—overview, intellectual merit, broader impacts—are clearly labeled. For non-NSF summaries, these labels could easily be removed.

Role of Winter Water Relations in Determining the Upper Elevational Limits of Three New England Conifers

Overview: Winter desiccation is recognized as an important stress factor in coniferous forests, and it may limit conifer distribution. Most research to date has focused on desiccation at alpine treeline, whereas little attention has been given to its role in establishing the upper elevational limit of low-elevation conifers. Our objective is to test the hypothesis that winter water relations limit the upper elevational range of low-elevation evergreen conifers in New England. This will be the first study to examine desiccation stress in non-subalpine conifers. The winter water relations of three low-elevation conifers will be examined: white pine (*Pinus strobus* L.), eastern hemlock (*Tsuga canadensis* [L.] Carr.), and red pine (*P. resinosa* Ait.). Each of these three species differs in its habitat preference and growth strategy. Preliminary results indicate that older foliage in each species can reach water levels expected to cause desiccation damage. Our approach will use physiological measurements of trees (relative water content, water potential, and cuticular resistance) collected near the upper elevational limit of each species during the winter to assess desiccation stress. These data, along with micrometeorological data collected at field sites, will be used to predict winter water relations. We will test the following hypotheses: (1) water levels in foliage near the upper elevational distribution of each species will approach or fall below lethal desiccation levels; and (2) cuticular resistance will decrease over the course of the winter. Even if this work does not support these hypotheses, the understanding of conifer responses to winter climate will be greatly increased.

Intellectual Merit: This study will be of value to plant-stress physiologists and plant ecologists. It is unique in that it will combine field assessments of desiccation with micrometeorological measurements in a model, allowing plant-water relations to be explicitly coupled to climate. Such an approach sets the stage for future studies of limitations by winter desiccation, using other species and under conditions imposed by a changing climate.

Broader Impacts: A broad societal benefit will be realized through increased understanding of how plant-water relations are coupled to climate, particularly within coniferous forests near populated areas in the contiguous USA. One graduate student will be supported on this project to supervise a group of undergraduate field assistants, including three women and several underrepresented minority students. This will integrate field science into the education of a diverse audience, furthering their understanding of biological and environmental processes and helping to train young scientists. The PI and graduate student will also provide outreach through public presentations both on and off campus.

Source: R. L. Boyce and A. J. Friedland (modified with permission of the authors)

Here is another summary that combines many of the important features we have discussed.

Neural Network Model for Chemotaxis in *C. elegans*

Overview: This research addresses the question of how the brain uses sensory information to select the most effective behavior in a given situation. This question is addressed by studying the nematode worm *C. elegans,* an experimental organism whose compact nervous system of only 302 neu-

rons is unusually well suited to investigating relationships between brain activity and behavior. The main focus of the research is to build and test a computer model of the nematode's neural network for chemotaxis, a simple yet widespread form of spatial orientation behavior in which an animal finds food, shelter, or a mating partner by directing its locomotion toward the source of an odor or taste.

Intellectual Merit: The model will be used to test the idea that the nematode's chemotaxis network utilizes separate neuronal pathways to signal increases and decreases in sensory input, much like the visual system in higher organisms, including humans, and should provide new insights into how neural networks function to control adaptive behaviors.

Broader Impacts: Nematode chemotaxis is accessible to young scientists and the lay public alike. The PI hosts visiting undergraduates and high school students from underrepresented groups. University undergraduates have participated in this project from its beginning and will continue to do so. These researchers (currently two honors college students and two freshmen) do real science, including laser ablation of neurons and quantitative assessment of behavior. Simplified versions of the models developed in NSF-sponsored research are a prominent unit of the PI's course in computational neuroscience.

Source: S. Lockery (with permission of the author)

Exercises for Writing a Project Summary

EXERCISE 6.1. Before you write your own project summary, read and critique a number of others. For example,

modify a few sentences in the sample summaries provided in this chapter or in Chapter 5 to see whether you can improve them. Try adding hypotheses or working with the placement of the sentences that describe significance. Read the summaries out loud and ask yourself:

- "Is the writing easily understood?"
- "Are the topics well ordered?"
- "Are transitions smooth and clear?"

EXERCISE 6.2 Below we have constructed two versions of a project summary. See how you can improve on each version.

> Version 1. *Effects of Nutrient Additions on Red Spruce Health and Nutrition*
>
> The purpose of the proposed study is to determine the effects of nutrient additions on carbon fixation and foliar nutrition of high-elevation red spruce in the northeastern United States. Trees in this ecosystem are declining, a circumstance that has been attributed in part to a changing chemical environment. Earlier work has shown that nitrogen and sulfur inputs are quite high, and nitrogen saturation has been suggested as a cause of decline. Work from the southern Appalachians suggests that acidic deposition–induced calcium deficiency, perhaps coupled with aluminum mobilization, causes increased rates of respiration and reduced photosynthesis: respiration ratios which lead to reduced growth. Work with potted spruce seedlings from the South has confirmed this, and it is consistent

with patterns observed in the field. Preliminary data by our group suggest that in New Hampshire, 1) spruce respond positively to additions of nitrogen, and 2) there are adequate supplies of base cations. Data from New York suggest that 1) nitrogen additions reduce foliar growth, and 2) calcium is limiting. We recognize that some of these findings are, in part, inconsistent with previous findings, and thus we wish to extend our investigations.

We propose to conduct a field study using naturally grown spruce saplings on Mount Jefferson (White Mountains, New Hampshire, United States) and Mount Marcy (Adirondacks, New York, United States). Fertilizer treatments using N, Ca, and/or Mg will be applied over the three-year course of the study. Photosynthesis and dark respiration will be measured throughout the growing season to determine the response to different treatments. Foliar concentrations and contents of N, base cations, and Al will be analyzed to determine their effects on carbon fixation rates.

This study will increase our understanding of the impact of global changes in atmospheric chemistry on high-elevation red spruce–balsam fir forests. However, our research has potential significance beyond this particular ecosystem, for it will show how conifers in general respond to abiotic stress. Chronic levels of stress, such as those induced by global change, often initiate forest declines. The early stages of decline are often subtle and therefore overlooked, creating difficulty in identifying the onset of decline. The research proposed here will make use of a species that is known to be in decline, across a gradient from low to high levels of decline.

Source: A. J. Friedland

Version 2. *Effects of Nutrient Additions on Red Spruce Health and Nutrition*

Nutrient deficiencies and imbalances are known to cause problems in plant growth and metabolism. High levels of nitrogen and sulfur deposition in the northeastern United States are suspected of causing nutrient imbalances at higher elevations. Many hypotheses related to N, S, Ca, and Al have been offered to explain the decline of red spruce at high elevations in the Northeast. Preliminary data by our group suggest that in New Hampshire, 1) spruce respond positively to additions of N, and 2) there are adequate supplies of base cations. Others have suggested that Ca supplies may be limiting. We propose to conduct a field study using naturally grown spruce saplings on Mount Jefferson in the White Mountains of New Hampshire. Fertilizer treatments of N, Ca, and/or Mg will be applied over the three-year course of the study. Photosynthesis and dark respiration will be measured throughout the growing season to determine the response to different treatments. Foliar concentrations and contents of N, base cations, and Al will be analyzed to determine their effects on carbon fixation rates.

This study will increase our understanding of the impact of atmospheric deposition of pollutants on high-elevation red spruce–balsam fir forests, and it may provide information on how conifers in general respond to abiotic stress. Chronic levels of stress can initiate forest declines in other temperate coniferous forests.

Source: A. J. Friedland

The first version could be substantially improved. For example, findings are reported in a chronological or sequen-

tial order. "Work from . . ." and "Work with . . ." constructions become repetitive and are not the most integrative and synthetic way to present information. The questions and hypotheses are not explicitly stated, nor is the potential significance of the work clearly stated. One way to amend this abstract would be to delete most of the first paragraph, describe the general area of nutrient deficiencies first, and identify the unanswered questions more succinctly. The second version is better but still fails to articulate the hypotheses.

EXERCISE 6.3. Here are some other summaries from successful proposals that we obtained directly from the authors or downloaded from agency websites. All are quite forceful, but even the best summaries can be improved. Try to enrich each one.

Biochemistry of Fatty Acid Transport in *Escherichia coli*

In all organisms, fatty acids (FA) and their derivatives are components of membranes, are sources of metabolic energy, and are effector molecules that regulate metabolism. This research is on the transport of long-chain fatty acids (C14–C18) into the cell, followed by their enzymatic conversion to coenzyme A thioesters prior to metabolism. These FAs traverse the cell envelope of *Escherichia coli* by a specific, energy-dependent process that requires the outer-membrane-bound FA binding protein FadL and the inner-membrane-associated acyl CoA synthetase (ACS). ACS activates FAs concomitant with transport and results in net FA accumulation in the cell against a concentration gradient. Processes that

govern FadL-mediated long-chain FA transport across the outer membrane will be determined by i) evaluating the topology of FadL using limited proteolysis and protein modification and ii) defining the FA binding pocket within FadL using the affinity labeled long-chain fatty acid 9-p-azidophenoxy nonanoic acid (3H-APNA). The contribution of acyl CoA synthetase to long-chain FA transport will be evaluated by i) defining the ATP and FA binding domains within ACS using the affinity labeled ligands azido-(32P ATP and 3H-APNA, respectively), and ii) mutagenesis of the FadL gene at specific sites involved in CoA and/or FA binding. Studies are also being conducted to define protein-protein interactions between the membrane-bound (FadL) and soluble protein components of this transport system using Far Western analyses and by performing experiments with glutathione S-transferase (GST) and histidine fusion proteins. Soluble protein components may interact with FadL. The H1/FA cotransporter in the inner cell membrane, and acyl CoA dehydrogenase and acyl CoA binding protein in the cell cytosol, may bind specifically with ACS.

Source: P. N. Black (with permission of the author)

Assessment of the Severe Weather Environment Simulated by Global Climate Models

Overview: Severe thunderstorms and tornados are very important mesoscale weather events in the central United States because of their high frequency and intensity in this region and the damage and loss of life that they cause every year. Recently it has been shown that the frequency of favorable conditions for significant severe thunderstorms and tornados can be estimated for the United States and

other regions using global atmospheric reanalyses with spatial resolution on the order of 200 km and temporal resolution of 6 hours. Global climate models are unable to simulate severe thunderstorms and tornados because their spatial resolution is too coarse to be able to simulate such mesoscale events. However, they should be able to simulate the environmental conditions under which such severe weather develops, including abundant lower tropospheric moisture, steep mid-tropospheric lapse rates, and strong tropospheric wind shear. High space- and time-resolution data from control simulations with global climate models archived at NCAR [National Center for Atmospheric Reseach] will be used to estimate the frequency of favorable conditions for severe weather, as simulated by the models. The climatological distribution of the severe weather environment in the model simulations will be compared with that from the reanalyses, including the seasonal and geographical variations, and its inter-annual variability. *Intellectual Merit:* Outcomes from this research will include a detailed assessment of global climate model simulations of the environmental conditions determining severe weather. This will provide a better understanding of some of the causes of model problems with simulation of warm season intense continental convection. *Broader Impacts:* In addition to the scientific outcomes, the graduate student employed on this project will gain valuable training and experience in climate diagnostics, climate modeling, and severe weather, which will allow him/her to contribute better to future research and development in climate change and its impacts in the United States.

Source: D. Karoly and H. Brooks (modified with permission of the authors)

Specific Aims

As noted earlier, NIH proposals require the project summary to include "specific aims." Here are a few examples of specific aims.

> Behavioral and Physiological Responses to Anabolic-Androgenic Steroids
>
> Specific Aim 1: To establish the dose-response characteristics and the role of the type of intruder on the expression of AAS-induced offensive aggression in male and female mice. Female and male mice will be tested in response to different types of intruders for offensive aggression and following treatment with six doses of a cocktail of AAS that vary in their androgenic and estrogenic properties and are commonly self-administered by humans.
>
> Specific Aim 2: To determine if loss of androgen receptor (AR) or estrogen receptor (ER) signaling induced by pharmacological inhibitors interferes with AAS-induced aggression in either male or female mice. AAS can be metabolized in the central nervous system to both androgenic and estrogenic derivatives. The relative importance of AR versus ER signaling in mediating AAS-induced aggression in either sex is not known. We hypothesize that both AR and ER signaling will be involved in mediating AAS-induced aggression, but that AR signaling will play a more important role in female mice and ER signaling will be more important in male mice. We will assess offensive aggression in wildtype mice of both sexes treated with a cocktail of individual AAS in conjunction with the AR antagonist, flutamide, or the ER antagonist, CI-628.

Source: A. Clark and L. P. Henderson (with permission of the authors)

Collaborative Research: The Mixed-Race Household in Residential Space: Neighborhood Context, Segregation, and Multiracial Identities, 1990–2000

First, we intend to map and analyze the neighborhood geographies of mixed-race households in 1990 and 2000. This will provide answers to questions such as: Do the processes that generate and sustain segregation, as we currently understand them, apply to mixed-race households? Do mixed-race households live in segregated neighborhoods or diverse neighborhoods? And how does this vary with the race, class, or nativity of the partners?

The second aim turns the first inside out: instead of assessing the influence of segregated neighborhoods on the geographies of mixed-race households, this phase of the research drives at how much racial mixing within households contributes to racial mixing within neighborhoods. Segregation measures typically rely on counts of individuals in neighborhoods and ignore the mixing of groups in households. This part of the research asks how much neighborhood diversity is accounted for by mixing in households. And how rising rates of mixed partnering affect change in levels of neighborhood scale segregation.

Source: M. Ellis, S. Holloway, and R. Wright (with permission of the authors)

Project Summaries on the Web

While writing and revising this chapter we read hundreds of project summaries from successful grant applications that were funded by U.S. agencies—we focused mainly

on summaries from NSF, NASA, NIH, and the U.S. Department of Agriculture. The summaries were from a variety of scientific fields, such as environmental science, ecology, molecular biology, earth sciences, atmospheric sciences, and neurobiology. While the summaries varied greatly, we found many similarities and incorporated these into the suggestions presented in this chapter. For example, all authors specified their research questions and explained the significance of their research topic. By perusing published summaries yourself, you can decide which styles and approaches you prefer. The listed web addresses, accurate as of press time, provide access to summaries of funded grants from federal agencies. These sites also provide suggestions and requirements regarding proposals:

- National Science Foundation (NSF): http://www.research.gov, http://www.nsf.gov, https://www.fastlane.nsf.gov
- National Aeronautical and Space Administration (NASA): http://www.grants.gov or http://www.nasa.gov
- National Institute of Food and Agriculture (NIFA) of the U.S. Department of Agriculture: http://cris.csrees.usda.gov
- Environmental Protection Agency (EPA): https://www.epa.gov/research-grants

- National Institutes of Health (NIH): https://projectreporter.nih.gov

Key Points

1. A good project summary tells the reader what you're going to address, how you're going to address it, and why it is important.
2. It is imperative to understand and adhere to the precise requirements set forth by the funding entity for formatting your project summary.
3. The project summary establishes the tone for the entire proposal, so be clear and concise while aiming to capture the reader's interest.

Homework

Using the criteria for the two-paragraph model, create an outline of your project summary using these steps. Once you have an outline, you can polish it into a full project summary.

1. List one or two phrases that describe the broader context of your research.
2. List your research questions. (You can convert these questions into statements of testable hypotheses or objectives later in the process.)

3. Write one or two phrases describing the gaps in current knowledge.
4. List your preliminary results, if applicable.
5. List or describe the methods you will use to test your hypotheses.
6. List any techniques, field sites, species, or subjects that will be used in your study.
7. List your expected results.
8. List advancements made by and implications of the expected results.
9. List the broader impacts of your study, including societal benefits, number of students supported, and so on.

CHAPTER 7

Objectives, Hypotheses, and Specific Aims: An Exhaustive List Is Exhausting

> A common problem I encounter when reviewing proposals is that either the big picture objectives are not stated or there is not enough detail provided to answer the who, what, when, where, and how within the specific aims. Proposals that strike a balance between these two endpoints capture my attention and keep me engaged throughout my review.
>
> —Sora Kim, Life and Environmental Sciences, University of California–Merced

A clever title, a strong and exciting significance statement, and a well-crafted project summary will be convincing only if the research objectives and tests are carefully constructed, explained clearly, and efficiently organized. If your objectives and tests are ill conceived, poorly stated, too numerous, or absent altogether, it is unlikely that your proposal will be successfully funded. And once your proposal is funded, having clear, efficient, and carefully constructed objectives and tests will make it easier to successfully accomplish the work.

You should generally develop your objectives and hypotheses or specific aims before you begin writing your proposal. If they are still fuzzy, you will find them difficult to explain, and you should spend more time refining them. Most readers of this book have probably already identified a series of objectives and associated hypotheses. Moving forward, your goal is to articulate those ideas in writing and to place them into a proposal. A key aspect of this process is making sure that the hypotheses are consistent with the significance statement and linked properly to the objectives. In this chapter, we show you how objectives, hypotheses, and specific aims are different and how to link them together and place them in your proposal.

Distinguishing Objectives, Hypotheses, and Specific Aims

In many ways, objectives, hypotheses, and specific aims are similar. However, you should understand the differences and functions of each so that you know how and when to use them.

Objectives are usually broad, scientifically far-reaching aspects of a study. Sometimes they verge on significance statements. In some fields, objectives are synonymous with goals. If both a significance statement and objectives are included, the objectives generally are more focused. Objectives

can also pertain primarily to contributions or novel uses of the data within the scientific community. The sample objectives listed here are modified from actual proposals.

- To further our understanding of how global climate change might affect freshwater-lake plankton communities
- To lead to more informed policy decisions about the effect of electromagnetic radiation on humans residing near high-voltage power lines
- To understand how cell division and differentiation are regulated by extracellular and intracellular signals
- To evaluate mechanisms leading to species coexistence in marine intertidal communities and compare magnitudes and scales of effects
- To provide the first complete database for the assessment of toxic metals on reproduction
- To develop an analytical framework for classifying brain potential analysis of motor function and decisions

Hypotheses are usually a set of testable conjectures. A well-formulated set of hypotheses leads directly to the experiments and sampling program that form the basis for the research. It is important to strike the proper balance between

too many hypotheses and too few. If you present too many, your proposal will seem unfocused, and readers will be less likely to find your ideas engaging. One of us once wrote a proposal with twenty-seven hypotheses. Reviewers were not dazzled with the breadth and depth of thinking; rather, they were baffled and bored. They also perceived a lack of focus—no surprise! After the proposal was rejected, the program director suggested reducing the number of hypotheses to five or fewer. We agree with that general recommendation, though there is no magic number for how many hypotheses to include.

Below are some hypotheses adapted from actual proposals. Is it apparent how these hypotheses differ from general significance statements or objectives?

- Lead is complexed by a chelating agent associated with adventitious roots, transported across the membrane, and stored in the inner cortex.
- Channel roughness is greater, and velocity, stream power, and shear stress are lower, in restored reaches versus unrestored reaches.
- Differences in temperature and humidity among sites persist across years, despite natural yearly variation in climate and other environmental variation.
- Zinc can displace other metals on enzyme active sites.

- Mineral weathering in the lower soil horizons provides more than 80 percent of the cations lost from the ecosystem to stream water.

Each of these examples tells you something specific that is expected to occur and can be tested to see if, in fact, it does occur: each is a hypothesis! Standing alone, however, none of these statements tells you why the specific process is important (significant) or what the broader goal (objective) is.

Specific aims are conventional in proposals such as those submitted to NIH and some other agencies. Generally, two to four are included in their own section. Each specific aim typically focuses on a particular question or hypothesis

"'HYPOTHESIS' IS A STRONG WORD. I'M CALLING IT A HUNCH."

and the methods needed and outputs expected to fulfill the aim—think of it in terms of the who, what, when, where, and how. The rest of the proposal is organized around each of the aims. The most effective proposals often use the significance statements to unify the specific aims and to establish a progression or a funnel from one to the next. As with objectives and hypotheses, there should not be too many specific aims, and they should be concise and easily understood if they are to be successfully conveyed to the reader.

Specific aims are usually numbered or bulleted to help the reader differentiate them. Here are some specific aims that we have modified from actual proposals.

- We will determine the crystal structure of all six minerals in the source rock.
- Using the high-resolution structure of a full-length dynamin protein, we will investigate the protein's global molecular mechanism and determine how it regulates itself.
- We will establish differences in temperature and humidity among sites over time.
- We will determine whether the organism promotes biofilm formation by secreting an inhibitory compound.

Additional samples of specific aims are given in Chapter 6.

Linking Objectives and Hypotheses to Your Significance Statement

Although objectives, hypotheses or specific aims, and the significance statement refer to different key features of a research proposal, their content is tightly linked, and they must work well together. Each relies on the others for its validity and purpose. The significance statement is the most general and far-reaching description of the research, objectives are usually more focused, and hypotheses or specific aims are even more specific than the objectives. In addition, objectives, hypotheses, and specific aims are more likely to identify particular processes, organisms, or locations than are significance statements.

To illustrate the relationships among significance, objectives, and hypotheses/specific aims, we return to Example 1 in Chapter 4 (an excerpt from a proposal by F. M. M. Morel). In this example, the significance statement introduces the topic of metal pollution and its major effects on agriculture and other ecosystems as the overall focus of the study:

> Understanding how metal pollutants affect crops and forests is obviously of great importance to U.S. agriculture.

One of the objectives in the same proposal identifies the metal pollutants being studied as coming from smelters and being airborne:

> [We wish to determine whether] in areas of high metal pollution, such as those near smelters, plants are exposed to

> metal stress through direct airborne pollution or [indirectly] through accumulation in soils.

Later on, the author presents this hypothesis, which names the metals as nickel and copper, the mechanism for pollution as atmospheric deposition, and the focal plant species as paper birch (*Betula papyrifera*):

> To investigate the hypothesis that current atmospheric deposition of nickel and copper aerosols is the dominant source of metal stress in vegetation surrounding Sudbury, Ontario, seedlings of *B. papyrifera* will be placed at each sampling location.

Note how the author becomes increasingly specific in the move from significance to objectives to hypotheses and how each is closely linked to the others.

Here is another illustration of the progression. This significance statement is broad in scope and relates to a problem of international concern, global climate change:

> We wish to understand the biological implications of projected increases in global average temperatures on fish populations.

The objective is much more precise and is directed to a particular type of system (salmonids on the rearing grounds), yet it remains somewhat inclusive (neither regionally focused nor species specific):

> We will quantify responses of salmon to predicted increases in summer temperatures in their rearing grounds.

Finally, the two hypotheses that derive from this objective lead directly to an easily identifiable set of experiments or measurements. They are species specific and address certain demographic traits and rates:

> An average water temperature increase of 18C in May will advance the hatching date of Atlantic salmon by approximately two weeks.
>
> Advancing the hatching date of Atlantic salmon by two weeks will lead to a reduction in survival rates.

In this example the move from significance to objectives to hypotheses is also a move from broad to specific.

Here are some examples in the format of specific aims rather than hypotheses:

- We aim to characterize the effects of individual growth and metabolic rates in controlling the bioaccumulation of methyl mercury in fish.
- We aim to determine the biological consequences of arsenic-driven alterations in steroid-receptor signaling in all cultures.
- We aim to investigate the molecular-genetic alterations associated with chemical carcinogen exposure in humans to identify biomarkers of low-dose exposure.

Placement in the Proposal

Successful proposals often feature the significance, objectives, and hypotheses sections near the start of the proposal, but there is no stipulated location for them. In contrast, specific aims in NIH proposals usually make up the first section of the proposal. Whether submitting to NIH or elsewhere, authors typically introduce objectives and even hypotheses in the project summary or aims, and the objectives almost always appear in the significance section of a proposal. You need to strike a balance between presenting material early and appearing repetitious when you discuss the same material in greater detail in later sections. Many authors insert the hypotheses in a number of locations in a proposal, presenting greater detail with each mention.

In the following example, the general hypothesis is first stated in the title and then repeated with greater detail, and in a different fashion, in various sections of the proposal.

- *Title.* "The Role of Temporal Control Genes in Specifying the Timing of Events in the Nematode *C. elegans*"

- *Project summary.* "The broad goal of this work is to understand the genetic and molecular mechanisms of the temporal control of cell division and differentiation using the nematode *C. elegans* as a model."

- *Introduction and background*. "Animal development is a complex schedule of processes that are controlled by genetic and other factors."
- *Significance section*. "The *C. elegans* genes offer an opportunity to study the genetic and molecular mechanisms controlling cell division and differentiation, processes central to all multicellular development."
- *Research design and methods*. The hypotheses are presented in a preface to each set of experiments that are designed to test them.

Source: V. Ambros

Regardless of where you cite your objectives and hypotheses, and depending on the requirements of your funding agency or dissertation committee, you should use headings and subheadings to guide the reader and highlight the importance of objectives and hypotheses within the proposal. Headings and subheadings also make it easier for reviewers to find the objectives and hypotheses. One widespread problem we see is that some authors number their objectives or hypotheses in a confusing manner (e.g., "I.A.b.iii"), which can diminish the strength of the final work. This is a minor point, but as we've stressed elsewhere, a clear presentation of objectives and hypotheses is extremely important, and using numbers or bullets under appropriate headings and subheadings will help to focus the reader.

In addition, be sure to follow the conventions of your field for style, organization, and even the way you make your arguments within your objectives and hypotheses. For example, the practice in some fields is to use the traditional null hypothesis; that is, no matter what you think the outcome of your study might be, you state that there will be no effect—for example, "The test drug will have no effect on the population." In other fields, positive hypotheses are more acceptable—for example, "The test drug will reduce symptoms in more than 75 percent of the test population." Style of presentation may also vary across disciplines—for example, hypotheses are sometimes worded as questions rather than statements.

Exercises for Writing Objectives, Hypotheses, and Specific Aims

In the class on writing proposals, we concentrate heavily on constructing, deconstructing, and reconstructing each other's objectives, hypotheses, and specific aims. Reviewing your hypotheses and objectives with others may be one of the most beneficial activities you can pursue. We recommend that you solicit feedback prior to writing by presenting your hypotheses to colleagues and mentors to determine whether they are rigorous, testable, and engaging. If you're working alone, look for a few colleagues who are willing to

exchange ideas. Many departments and colleges on campuses have brown bag lunch groups or similar gatherings exactly for this purpose.

Use the following exercise to formulate a very tight set of hypotheses or specific aims prior to writing the accompanying text. This formulation step may take several weeks as you review the critical feedback on your objectives and hypotheses and then revise and restate. This exercise is a strong follow-up to the exercises in Chapter 4 for developing your significance section.

EXERCISE 7.1. Prepare a two-page summary or a ten- to fifteen-minute presentation of the objectives and specific aims or hypotheses of your study, focusing on the direct links between them. As in the previous exercises, justify the importance of your hypotheses with respect to the larger field of theoretical and empirical research as you presented it in your significance section. Hypotheses must be concise and easily understood, and the flow among the hypotheses must be logical. Work to develop a sensible progression and transition among ideas.

We again urge you to evaluate the example proposals you've collected, either on your own or with a group. In addition to considering logic and flow, also assess the style of presentation.

Key Points

1. Objectives refer to broad, scientifically far-reaching aspects of a study, while hypotheses refer to a more specific set of testable conjectures. Specific aims focus on a particular question or hypothesis and the methods needed and outputs expected to fulfill the aims.
2. Objectives, hypotheses or specific aims, and overall significance are tightly linked and must work well together. Each relies on the others for its validity and purpose.
3. There may be no stipulated location for the significance statement, objectives, and hypotheses, but they are usually featured near the start of a proposal. Many authors insert the hypotheses in a number of locations in a proposal, presenting greater detail with each mention. Be sure to strike a balance between presenting material early and appearing repetitious when you discuss the same material later in greater detail.

Homework

1. If you haven't done so already, now is a good time to find or start an informal group within your department or college where you can solicit feedback on

your ideas from your peers. If such a group doesn't exist, start a brown bag lunch group in your department that meets weekly or biweekly.

2. Using your concept paper or the significance statement you developed in Chapter 4, hone your objectives into clear statements.

3. Do the same to develop your hypotheses into clear statements.

CHAPTER 8

Lay the Foundation in the Introduction

> I spend more time on the first few pages than any other section. If reviewers lose interest at the outset, all the hours I've spent hammering out the details of the proposal will only get a quick look at best, resulting in a mediocre to poor score for all of my hard work.
>
> —Steven Anderson, Earth and Atmospheric Sciences, University of Northern Colorado

Once you have identified the significance of your research and developed your objectives or aims, your work begins in earnest: you must create the essential elements of what NSF terms "The Project Description" and NIH calls "The Research Strategy." The introduction or background is a major element of both the project description and the research strategy. The main goal of the introduction is to present necessary background material to support your objectives, hypotheses, and proposed research.

In your introduction you should review the current literature on your research topic and stress key references. This

is also where you introduce relevant conceptual, empirical, or theoretical models and discuss the need for new methods or technologies if they are pivotal to your research. To set the stage for your proposed study and to establish your ability to accomplish the task, include a summary of your own relevant prior research or preliminary results.

If your introduction is a success, readers will be eager to reflect on the research plan that you have devised to test your hypotheses and meet your objectives. We begin this chapter with a brief discussion of the section called "Results from Prior Agency Support" that is typically required by federal funding agencies. This section is usually included at the beginning of a proposal, before the significance section and the introduction. Then we discuss each of the elements that make up the introduction, provide approaches for developing them, and offer guidance on pulling them all together into a well-crafted introduction and overall project description.

Results from Prior Agency Support

A prior results section is generally meant to include results of research previously funded by the agency to which the current proposal is being submitted. If you are applying to the NSF, and you or any of your co-investigators have had any prior research funded by the agency, you will be required to summarize the results of the research in a section

specifically called "Results from Prior Agency Support." Typically this section appears as the first part of the project description, preceding even the significance section. In graduate dissertation proposals, this section is not needed; preliminary results can be effectively blended directly into an introduction section that includes background information.

Even if a prior results section is not required, including one is highly recommended if the current proposal is an extension or continuation of previously funded work or if a result or discovery from prior work is relevant to the proposed work. Reviewers of proposals are always asked to comment on an applicant's productivity and on the quality of his or her previous work, so this section may strongly influence the funding decision. Keep your prior research statement concise, citing your published work where appropriate. We advise using this section to establish your past success and productivity and to highlight previous results that have been insightful and that lay the groundwork for the new research. If you can't find specifics in the agency's proposal guidelines on the type and amount of information usually contained in this section, you should seek guidance from the agency's program officer. Remember that for most proposals space is at a premium. Allotting too much text to this part of the proposal will restrict the space that can be used to present other material. Avoid providing information that will distract from the proposal at hand.

If your prior work is not related to the proposed work but a statement is still required, keep the discussion short and consider putting it at the end of the project description, where it is less likely to draw attention away from the current proposal.

Provide a Strong Foundation for Your Research

Recall the suggested order of presentation of the project description from Chapter 3:

IV. Project description
  A. Results from prior agency support (this chapter)
  B. Statement of the problem and significance (Chapter 4)
  C. Introduction and background (this chapter)
    • Relevant literature review
    • Preliminary data
    • Conceptual, empirical, or theoretical model
    • Justification of approach or novel methods

As you can see, four main elements make up effective introductions: a review of literature related to your proposed research, a brief discussion of your preliminary data, a model or models to frame your research questions, and a justification of your approach or your use of novel methods. Basically, you must cover the key concepts, previous work, and important publications that will enable an informed

scientist from another field to understand the motivation for your research. At the same time, experts in the field should not find this section too elementary. An ideal introduction allows the reader to understand and evaluate the proposed work without needing to refer to previous publications on the topic—something that can be frustrating to a reviewer (Day and Gastel 2006). This is your opportunity to capture the attention of a review committee or funding agency. After reading a persuasive introduction, the reader should exclaim, "Of course! What a great idea for a research project. Why didn't I think of that?"

There is no one right way to organize your introduction, but we continue to suggest funneling from the general to the specific by starting with a general review of the literature and funneling to the details of your specific study. However, some authors build from the specific to the general. Try articulating your own arguments in each of these ways to see which allows you to be the most concise, logical, and interesting.

Set the Stage with Your Literature Review

Throughout your proposal you must make a case for the importance of your research; in the introduction you can reinforce its relevance and the need for it with a thorough, well-organized, and concise review of relevant literature. The literature review can set the stage for your research project

by telling the background story and demonstrating why your proposed work is vital. Use current and widely accepted references wherever possible to support your arguments and to channel the discussion toward your specific research objectives.

Bear in mind that you have limited space in which to develop your topic. Applying the precepts of *funnel* and *focus* will help you organize your literature review while being concise. Ask yourself if each concept or paper is worth citing. Avoid unnecessary details, digressions, and topics not directly related to the proposal. They can be distracting, and they may suggest that you have not clearly identified the key concepts and issues related to your proposal. We have read introductions that endeavor to provide background on all aspects of a topic except the one the investigator plans to study. For example, imagine a proposal on the effects of climate change on soil microbial decomposition. If the author were to begin the background section by reviewing climate change theory, changes in greenhouse gases over time, and the evidence for and against global warming, it would be difficult to guess where the author was heading. Without an effective funnel and without highlighted key arguments, the reader could be well into the proposal before the relation between climate change, soil moisture, and soil microbial decomposition is established.

New researchers often have much uncertainty about the use of references in research proposals. We discuss

references in detail in Chapter 12. For now, here are answers to a few common questions.

How many references should I include? Reviewers are more interested in the quality of references than in the quantity. It is vital to illustrate or support your major points with important references, but you do not need to include an exhaustive list of papers that illustrate each item you raise. Include the references that have guided the development of the field, and be sure to include any new references that are germane to your arguments.

Which references should I include? The literature review must appear thorough. Proposals are often criticized for not including key references, which we take to mean the most widely accepted or influential papers on a topic. If you want to establish a gap in the literature, you must be especially careful to do a thorough literature review—you do not want to say there are no published papers on a topic and then learn from reviewers that you missed references.

Will references to hypotheses that compete with my work diminish my arguments? To be thorough, you should incorporate both references that support your contentions and those that either conflict with your arguments or that may be difficult to resolve with respect to your arguments. New authors frequently ignore this aspect of proposal writing, but because many reviewers make a point of considering multiple sides of an argument, this omission can be fatal to a proposal.

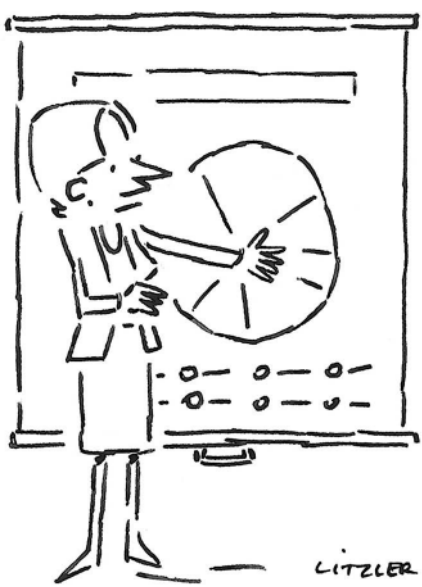
Should I discuss controversial papers? To be thorough, you may need to cite controversial material. If you do, be certain that you understand why the material is controversial and take special care if such papers provide the critical justification for your research. That is, if you use controversial material as a foundation for your own study, be sure to explain the relationship between your work and the controversial material and to show how the results of your research might be able to resolve some of the questions. Remember, if you cite controversial work as a foundation for your work, and a reviewer dismisses the controversial work as "unproven" or "unconvincing," then the basis for your proposed work may be questioned.

Do I need to justify my methods using the literature? If you are using a well-known method, you can save space in your proposal by referencing relevant literature. If you are developing and testing a new method, you should reference supporting literature that discusses the shortcomings of other methods and illustrates the benefit of a new method.

Establish the Novelty of Your Work with Preliminary Data

A prior or preliminary results section within the introduction is an appropriate location for your own unpublished, preparatory data. By placing your preliminary results here, you establish your competency or the likely success or

novelty of your proposed research. If you are a beginning researcher or are new to a particular field, you may not have published results from previous related work. However, even as a new researcher you may have generated preliminary data that should be included in the proposal. Avoid overstating the implications of your results or giving the impression that you have already solved the problem and don't need to do additional work. Either will significantly hinder your ability to make a case for your new project.



"I'D LIKE TO INTRODUCE YOU TO MY PRELIMINARY DATA."

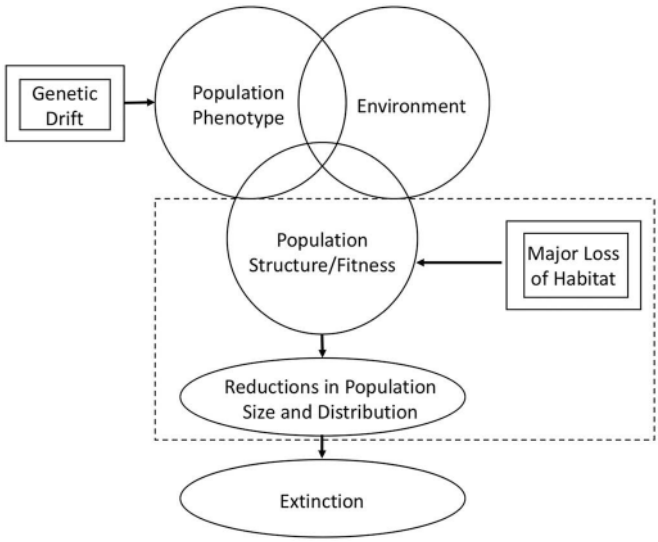
The Role of Conceptual, Empirical, and Quantitative Models

The authors of some of the strongest proposals use conceptual, empirical, or quantitative models to frame their research questions and design. Models, standard in some fields and less common in others, can be far more effective than words. Models are usually presented in the introduction and are often represented in the text with tables, figures, or sets of equations. It should be clear to the reader whether the model is your own or adapted from the literature. During the formulation of their research proposals, many scientists develop conceptual or analytical models that they publish as freestanding works.

Models have many different formats. They can be conceptual, empirical, or quantitative. Your choice depends on what you need to show.

Conceptual models, or theoretical models, are commonly used to identify the components of a study or the processes leading to and deriving from a central theme within a system. A "box model"—a set of boxes and arrows that shows how your research question fits into a larger picture—may be effective.

Empirical models, or calculations based on observations, are also useful for synthesizing introductory and conceptual material. Many successful investigators apply a computer



A box model showing possible consequences of anthropogenic habitat loss on population structure and fitness, distribution, and extinction. In this example, the dotted lines indicate the area that the hypothetical proposal will examine (modified from Gilpin and Soulé 1986).

simulation or a few simple calculations to data from their own work or from the literature to generate new figures, graphs, diagrams, or synthesized data that provide motivation and perspective for the current research. These are particularly effective when you do not have your own preliminary data but want to demonstrate that your ideas are feasible. The need to provide details about the model, such as equations, parameter sources, constants, or hierarchical organization, depends on how fully the model predictions form the basis of your proposed research. However, you must be

sure that your model does not raise more questions than it answers. We urge you to ask colleagues who have used models to provide critical feedback on this part of your proposal.

Quantitative models can also be used to generate analytical solutions or predictions resulting from more formal mathematical expressions of conceptual or qualitative models. However, avoid complicated or untested models; such models should be published first in a peer-reviewed publication. The introduction is one potential location for a quantitative model; the methods section is another. (Chapter 9 discusses the methods section in more detail.)

If the thrust of your proposal is modeling, then you must present most of the details in the methods section or in a section devoted to the model. If your model is a tool used to interpret or apply results, however, it is probably sufficient to present a short paragraph describing it, along with a few references to more detailed descriptions of how it is used. If you have modified a model from the literature but have not published your modifications, you should describe, if not show, your changes.

Emphasizing Your Ideas and Justifying Your Approach

Should you include objectives and hypotheses in the introduction? It is common for the introductory section to

conclude with a list and brief discussion of objectives and hypotheses. These should derive easily from the background material just presented. However, some people prefer to include objectives and hypotheses in the research plan (see Chapter 9) or as a separate element of the proposal; in either case, the objectives and hypotheses must mesh logically with material in the introduction. Specific aims in NIH-type proposals don't usually need to be repeated. However, some authors organize the entire background into separate sections with headers for each aim.

In some instances, it is necessary to provide literature support for the employment of a particular approach or method or for the use of a special type of instrumentation. If any of these are controversial or novel, the literature and preliminary results that support your project should be featured in the introduction and background. Your evidence for the successful use of your approach, method, or instrumentation will be of special interest to reviewers, who need to assess the feasibility as well as the importance of the proposed research.

Crafting the Introduction

We emphasize three guidelines to follow when writing and organizing the introduction:

- Do not make this section too long.
- Focus on the important points and establish their relevance to your proposal.
- Use schematics, models, headings, and formatting to funnel the reader and to show the direction the proposal is taking.

Be sure to watch the length of this section. Inexperienced writers tend to include too much background material in their introductions, which makes them too long. The background should reinforce the need for the proposed work but avoid tangential material that dilutes the message. A length of three to four single-spaced pages should be adequate. Remember, the introduction is 25 percent or more of an NSF-type fifteen-page proposal.

To take advantage of the limited space, you must choose your material wisely so you do not dilute your message. Organize your points strategically to funnel the reader to your research, and break up text with headings, figures, and tables. Explain to the reader why you are presenting details by providing section and subsection headings, topic sentences, transitions, and written road maps such as "In the following section we develop a framework for . . ."

Parts of the background may be neatly summarized with a figure or table. Figures are impressive if you have made

them yourself and if they synthesize a number of different papers culled from the literature. Reviewers often prefer to examine a figure or table embedded in the text rather than read two or three paragraphs of prose.

One final word of caution: resist the impulse to finalize the background too early. Novice writers may compose and finalize the background before they have finalized their hypotheses or specific aims. While it is productive to gather essential background material early in the development stage, ultimately you will need to pare down and focus the background material to suit your exact hypotheses and aims. It is often harder to rewrite or edit a section than it is to wait until you know what you want to include before writing it in the first place.

Exercises for Writing the Introduction

EXERCISE 8.1. As usual, the best preparation is reading and critiquing other proposals. You may also find it useful to consider good review papers as templates for an effective background. A strong comprehensive review brings literature together to support a set of central conjectures or to reveal a vital gap in knowledge. In this way, it is similar to a proposal background.

EXERCISE 8.2. The exercises presented in Chapter 4 led to the development of the conceptual framework, the project

summary, and underlying qualitative or quantitative models. By requiring you to frame your questions within the context of the existing literature or your own preliminary results, they also prepared you to draft your introduction. In particular, EXERCISE 4.3 promoted the construction of a model or series of models to identify the key relations among processes that form the basis for a model in your introduction. At this point, you might find it useful to go back and review those exercises.

EXERCISE 8.3. Another exercise that is usually instructive is to summarize the elements of your research design schematically. Try constructing several diagrams or figures that could help you formulate a verbal description of your research plan. You might then consider using one of these to help frame the introduction for your project.

Key Points

1. The introduction contains four important sections that make up the bulk of your project description: literature review, preliminary data, models that describe your research, and justification of your approach or methods.
2. A description of your results from previous funding should be included, either before your introduction begins or within it. This is advisable, even where not required.

3. In writing the introduction pay attention to its length and focus on the important points. Use schematics, models, headings, and formatting to funnel your reader.

Homework

1. The exercises and homework assignments in earlier chapters, as well as the exercises in this chapter, have prepared you to write your introductory section and overall project description. Gather together your previously developed work, such as the model from EXERCISE 4.3 and your significance statement, and organize the pieces in the context of your project description and introductory section.

2. Once you have created the framework for your introductory section, identify any missing components, such as a succinct description of your preliminary data or a literature review.

3. Begin developing these missing components and add them to your introductory section. You will probably have to refine the components that you developed earlier. Once they are completed, you'll have a substantial part of your proposal nearly complete! When you have completed your own introduction, have others evaluate it.

CHAPTER 9

Experimental Design and Methods: What Will You Actually Do?

> Design your experiment so that it leads to publishable results. If you rely on making a single complex measurement and that complex measurement ultimately doesn't work, then the whole thing falls apart.
>
> —Stephen C. Peters, Earth and Environmental Sciences, Lehigh University

Your introduction should give your reader a solid appreciation of the background to and importance of your proposed objectives and hypotheses or specific aims. After it is complete, the next big step is to craft the unit identified as the "research plan." This element contains the details of the implementation, analysis, and interpretation of your study. This is where you convince the reader that your project can be accomplished. After you complete this section to your satisfaction, you will have nearly completed your proposal! The remaining tasks will be much less arduous.

Again, recall the suggested order of presentation of the project description from Chapter 3:

IV. Project description
  A. Results from prior agency support (Chapter 8)
  B. Statement of the problem and significance (Chapter 4)
  C. Introduction and background (Chapter 8)
    • Relevant literature review
    • Preliminary data
    • Conceptual, empirical, or quantitative model
    • Justification of approach or novel methods
  D. Research plan (this chapter)
    • Overview of research design
    • Objectives or specific aims, hypotheses, and methods (this chapter and Chapter 7)
    • Analysis and expected results (this chapter and Chapter 10)
    • Timetable (Chapter 11)
  E. Broader impacts (Chapters 6 and 10)

The research plan is usually divided into a number of sections, including design, methods, and analysis sections. However, you have to strike a balance between conveying enough details without overwhelming the reader. When writing this part of your proposal, be sure to ask yourself, "Too much, too little, or just enough?" Consider these crucial questions that thoughtful reviewers will ask as they assess your plans:

- "Are these the correct and best methods to answer the specific questions?"

- "Are the methods proven and properly cited?"
- "Are the methods feasible given the time and support available?"
- "Is the precision or extent of the study appropriate and sufficient to answer the questions, hypotheses, or objectives?"
- "Are the investigators competent in the use of the techniques they propose to employ?"
- "What critical and innovative outputs will result from this study?"

In this chapter, we cover the organization of the research plan as it relates to your research design and considerations to bear in mind as you describe your methods.

Organizing the Research Plan

Organization of the research plan differs widely among writers and among disciplines. The goal is to keep the reader focused on the overall significance, objectives, specific aims, and hypotheses while providing important methodological, technological, and analytical details. There are numerous ways to achieve this goal. Here we provide two approaches that we have encountered in successful grant applications.

Approach 1. In this approach, the overall research strategy and scope are presented in a short opening section

consisting of a paragraph or two. Typical titles for this opening section are "Research Design and Scope," "Experimental Design," "Research Protocols," or "Strategic Plan." The opening section serves to keep the reviewer focused on the research objectives. Giving an overview can be particularly helpful when organizing research plans with several distinct elements, each of which requires different methods and approaches. The different elements can be labeled with subheadings such as "Study System," "Sampling Program," "Analytical Techniques," and "Field Experiments." When you use this approach, you will describe, at the start, your overall plan for linking the different elements.

Information must flow logically from the introduction to the research plan. Provide evidence that your design is the best and most appropriate way to solve the questions that you have identified as significant. Do not simply repeat what has already been said. You may find it helpful to save space by including a table of key hypotheses, or a figure that conceptually links hypotheses and methods to specific objectives or aims.

Typically, the opening section is followed by a section on the methods to be used and is titled something like "Methods and Materials" or "Experimental Protocols." The order of presentation of methods should match the order in which the objectives and hypotheses are presented elsewhere in the proposal. Tables for complicated procedures may be helpful,

and appropriate references to common methods are essential. Be sure to make clear which methods pertain to which questions or hypotheses.

A third section should provide details on the analysis of the data and the expected results. This section often has titles such as "Analysis and Results," "Analytical Approach and Results," or "Data Analysis and Expected Results."

The following outline lists the steps for the Approach 1 format for the research plan:

D. Research plan
   1. Research design and scope
   2. Methods and materials
      - Sampling procedures
      - Culturing methods
      - Experimental protocols 1, 2, 3, etc.
      - Technical procedures, etc.
   3. Data analysis and expected results

Approach 2. In this approach, each objective and its associated hypotheses are presented with the study plan and methods that will be used to test them. For example, imagine that you have several objectives with their own derived hypotheses. In this format you present each objective separately, followed by the specific hypotheses and methods to examine them. This sequential approach can be effective for clearly communicating how you'll test each hypothesis because each test follows directly from each question. However, in some cases you may find that you need to

repeat material from previous methods, which may become tedious. With this format, you may include the analysis right after each methods section, rather than including it in a separate section.

The following outline lists the steps for the Approach 2 format for the research plan:

D. Research Plan
1. Objective or specific aim 1
Hypothesis 1A
• Methods, materials, and protocol for H1A
• Data analysis for H1A
Hypothesis 1B
• Methods, materials, and protocol for H1B
• Data analysis for H1B
2. Objective or specific aim 2
Hypothesis 2A
• Methods, materials, and protocol for H2A
• Data analysis for H2A
Hypothesis 2B
• Methods, materials, and protocol for H2B
• Data analysis for H2B

The approach that you use will ultimately depend on several factors, including the targeted funding agency, the format required or typically used, the number of objectives, hypotheses, and different types of methods you have, and your personal preference as you develop your proposal writing style. Whatever approach you choose, you must tie your methods and analyses back to your objectives and hypotheses.

What to Consider while Writing the Methods Section

In your research design and methods sections, you must show your readers that you have an achievable research plan. You should also highlight and defend any innovative methods. That is, crafting a narrative of the methods you will use is not enough; a successful proposal also addresses common concerns and considerations related to the methods it presents. Reviewers will carefully weigh this section when they consider the pros and cons of the research design. Below, we discuss several questions that reviewers typically ask themselves as they read proposals. As you write your methods section, consider how these questions might be answered, and revise the section until what you have written leads to satisfactory answers. This focus will help convince your eventual reviewers that your plan is achievable.

Are these the correct and best methods to answer the specific questions? Perhaps the most decisive question that a reviewer will ask is whether the methods are the most fitting for meeting your objectives and testing your hypotheses. Although matching methods to objectives sounds simple, and it can be, some reviewers contend that inappropriate methodology is one of the most common flaws in unsuccessful proposals.

Consider a hypothetical example:

> An investigator proposed to measure the effects of aluminum on the reproduction and mortality of a particular species of fish. The author convincingly presented the need for and value of this information, so reviewers were initially positive about the study. But as they read the design and methods section of the proposal they detected what became a fatal flaw. The investigator planned to measure the total level of aluminum in fish tissue. Yet recent research had revealed that aluminum occurred in several chemical forms (species) in nature and that not all forms were toxic to fish. Moreover, in some situations the toxic species of a metal had no relation to its total concentration. The reviewers concluded that the investigator would be making virtually meaningless measurements, and they now questioned whether the author understood current developments in the proposed field of study.

In this simplistic example, the questions and hypotheses were sound, but poor methodology raised questions about the value of the work and the competence of the scientist, which resulted in a failed application.

Other problems can originate with a poor choice of methods, especially when there is no agreement in the field about the best and most suitable approach. For example, the fastest and most conclusive procedures will generally be favored over others that also are feasible and workable unless there is a serious drawback to their use. Limited resources, prohibitive costs, or lack of physical access to cutting-edge

technology or particular instruments may prohibit your use of state-of-the-art or favored techniques. You may propose a less costly method for solving a problem, but it must be equally precise and reliable or reviewers are likely to object even if they are sympathetic to your situation. When cost or limited access to technology or equipment is relevant, it can be beneficial to raise the issue during the initial introduction of your ideas and approach.

Are the methods proven and properly cited? Not all reviewers of your work will be experts in your field, so you must provide evidence for the suitability of the proposed methods. You should not need to describe well-tried techniques in depth; proper citation of established procedures and their application is sufficient. Reviewers may respond favorably to innovative methodology and novel techniques, but new or controversial procedures generally require justification and affirming support. The most convincing support is documentation of their feasibility. In our experience, proposals that require adaptations or development of new techniques are most successful when preliminary data or calculations are provided to suggest the likely success of the procedures. In some cases, a full proposal will not be awarded, but a small amount of funding will be provided specifically to generate preliminary data to demonstrate feasibility. One of us once received 5 percent of our initial request to do this. The need for preliminary data is a well-appreciated conundrum in science—you need

some results to prove that your work is worthy of funding, but you do not have the funds to conduct the work until you receive the grant. One way to resolve this problem is to collaborate with scientists already generating results of the type you desire. Another way is to apply for a small development grant at your institution or funding agency.

Are the methods feasible given the time and support available? Your methods may be feasible—they will do what you say they will do—but they may be impractical to implement. What you propose to do must be reasonable given your time and resources. New researchers tend to err on the side of proposing too much rather than too little. Graduate students sometimes conceive projects that would require several dissertations to complete. This might be acceptable to a tolerant graduate committee, but a funding agency is unlikely to accept a serious mismatch. Proposing too much casts doubt on your judgment, and it does not provide reviewers with satisfactory information on how you prioritize the tasks. It is more effective to educate the reviewers and convince them that you can do what you say you will do. The proposal timeline will also be scrutinized for this purpose. (See Chapter 11 for more on timelines.)

Is the precision or extent of the study appropriate and sufficient to answer the questions, hypotheses, or objectives? When you have established that your questions will be tested properly by your proposed methods, critical reviewers will also

assess the way you intend to handle your data and conduct statistical analyses. (Refer to Chapter 10 for more on analysis of results.) An effective proposal demonstrates that you intend to use the best and most powerful analytical techniques suited to your experimental design, sample size, and replication. It may be useful for you to consult with colleagues and advisors about your data analysis. In some disciplines, mistakes in data analysis are among the top reasons that a proposal fails to be funded.

Are the investigators competent in the use of the techniques they propose to employ? Reviewers will want assurance that you and your collaborators have the technical expertise to accomplish the research. In most areas of study, at least some laboratory techniques or field methods are difficult, expensive, or time consuming. If this applies to your proposal, you must prove not only that the means are appropriate and feasible but also that you are qualified to use them. The testimony of people with whom you have studied or trained, your preliminary data, and your peer-reviewed publications will be used to evaluate your competence with a given technique or method. If you are trying something novel and are also new to a discipline, you may be unable to prove your skill in a proposal. In this case, you may wish to collaborate with someone who is well regarded in the field and demonstrate that this person has agreed to advise you or to conduct calibration and cross-checking of samples, methodology, or

techniques (Reif-Lehrer 2005). A more formal collaboration such as a subcontract may be best in circumstances where your ability to conduct difficult work may be questioned. Many agencies encourage multidisciplinary collaboration, and this is an excellent justification for working with someone who complements your abilities.

What critical and innovative outputs will result from this study? Every effective proposal summarizes expected outputs. It is common to see proposals with a section titled "Expected Results." The projected outputs of your study must be considered realistic and important. In some cases, investigators include a specific set of items that they will produce (a gene library, a collection of specimens, a new drug therapy), while others generate less tangible outputs (advancing our knowledge of a topic, testing an untested theory). Outputs should follow directly from the significance statements and in some sense address how the actual study is pertinent to the broadest stated goals. Be aware that although you'll probably describe your expected outputs in their own section, reviewers will be assessing your methods with the expected outputs in mind.

If you address these typical reviewers' questions in your methods section, you will have anticipated common concerns, presented a clear and unified vision, and created a persuasive methods section as part of a competently prepared proposal.

Deciding What to Include

The methods section of a research proposal differs from that of a scientific manuscript in a fundamental way: proposals must include enough information for a reviewer to critically evaluate your methods, but they do not have to provide all the detail needed for someone to duplicate your work. There are times when you should list the details of a specific method—particularly if you are relying on unpublished or novel procedures—but often it is appropriate simply to cite an earlier work or standard technique. Presenting too much information can diminish the punch of your proposal, but presenting too little may prompt readers to question your ability to conduct the work. Consultation with colleagues or even the program director at specific agencies can help you decide what is appropriate in your case. Just as you evaluate the contribution of each reference, so, too, should you question the need for each detail of your methods. (References are discussed more in Chapters 8 and 12.)

Because each proposal will have a specific set of measurements or experiments appropriate for the research it describes, we do not provide a checklist of items for this portion of a research proposal. A few elements common to most methods sections are listed below. However, we suggest that you refer to proposals in your own area for more specific information about what to include.

- *Outline of proposed research.* Most proposals include an outline or brief description of the overall methodological approach. This functions both as a road map and as a justification of your approach.
- *The study site, the species, the system.* If your work depends on a certain organism, location, gene, model system, chemical product or process, or on a specialized piece of equipment, you should describe it here. Supply adequate information to allow the reader to understand the system in which your work will take place. This is especially important for reviewers who are not experts in your field. Discuss the background of the reviewers with the program director to determine how much detail to provide.
- *Methods and techniques.* If your techniques are well known, it may suffice to write, "Collection and analyses will be conducted following the methods of [name the researcher here and provide a reference]." If the methods are new, have been developed by you, or are not well known, provide a thorough description and documentation. Do the proposed methods have any particular limitations that might affect the interpretation of your results? Explicitly state those limitations and their implications. It is much better for you to point them out than for a reviewer to raise the question.

- *Data analysis*. If preliminary data are available, show how you will use or analyze them to reach your objectives or test your hypotheses. If such data are unavailable, consider culling data from the literature to show how you expect the results to turn out and to show how you will analyze your data when they are available. Complete a table or diagram, or run statistical tests using the preliminary or "synthesized" data. This can be a good way to show how you would interpret the results of such data.
- *Storage and archiving of samples and data; integrity of data*. Describe your intention to save, store, or archive physical samples or data and any specific methods that you would employ to do this. You will likely be required by your funding agency to make data or samples available to other investigators. For NSF proposals, according to the current PAPPG, you will also be required to submit a separate data management plan with your proposal as a supplementary document. Even if making your data accessible to other investigators is not required, planning to do so may strengthen the proposal. You may also be planning a follow-up or comparison study. If so, maintaining the integrity of the samples or archived database is critical.

Exercises for Writing the Methods Section

EXERCISE 9.1. Once again, our first suggestion is that you critique other proposals in your immediate research area. Consider the extent to which they provide information and the way they present it. For this round of critiquing, act as a reviewer and use the questions listed above. If possible, examine both successful and unsuccessful proposals. Unsuccessful proposals may provide some guidance on ineffective presentations or perceived weaknesses. Some colleagues may be willing to share samples of review comments from both successful and unsuccessful proposals. Often the reviewers are explicit about the key weaknesses that frequently occur in the methods and approach sections.

After you have looked at some proposals in your research area, try the next two exercises.

EXERCISE 9.2. Critique the following excerpts from the research design sections of two successful proposals. Determine if they satisfactorily answer some or all of the common reviewer questions listed above on what to consider when writing the methods section. (The sources cited are pertinent only to the sample proposals and are not included in the references listed at the back of this book.)

> *Example 1.* Once the precise bases that interact with the gene APETALA3 (AP3) are identified, we plan to make specific base changes by site-specific mutagenesis (Kun-

kel et al. 1987). Once the mutations are made, we will clone them back into an otherwise wild-type AP3 promoter fused to b-glucuronidase (GUS). These constructs will then be transformed into the plant *Arabidopsis thaliana* and crossed to see whether they activate the GUS reporter. If single base changes destroy the ability of AP3 to autoregulate, that would provide convincing evidence that the mutated sequence mediates autoregulation.

Source: T. Jack

Example 2. Within each section of stream we will survey three to four channel cross-sections (Feldman 1981) from valley side to valley side, for subsequent hydraulic modeling. Surveying will be accomplished with a Topcon AT-F6 automatic level. We will measure gravel sizes on riffles, channel area, pool area, and bar area using standard techniques and those of Wolman (1954) and Hankin and Reeves (1988). . . . The effects of channel bed roughness (primarily a function of bed particle size and slope) will be determined using empirical relationships determined by Jarrett (1985) for steep cross-sections typical of high-elevation streams.

Source: P. F. McDowell and F. J. Magilligan

EXERCISE 9.3. This exercise follows from the exercises given in Chapters 4 and 7. Prepare a ten- to fifteen-minute oral presentation on the research design and methods for your research project. As in the previous exercises, emphasize the relation of the study to the larger field of theoretical and empirical research. It will be difficult to do this in

fifteen minutes, but by attempting it, you will be forced to be succinct and precise. You may wish to undertake this drill several times, for logical flaws and poor presentations are revealed by feedback from colleagues or classmates. A department brown bag lunch or weekly lab meeting would be an ideal venue for your presentation. Soliciting comments from people in peripheral disciplines can be especially helpful for distilling the jargon from your presentation.

Key Points

1. Successful proposals will keep the reader focused on overall significance, objectives, specific aims, and hypotheses while providing important methodological, technological, and analytical details that tie them all together.
2. Your research plan should contain the essential details of implementation, methods, analysis, and interpretation that you propose to use in your study. The research plan must convince reviewers that your project can be accomplished. To be sure of convincing them, consider the questions reviewers will ask when evaluating your proposal.
3. The research plan must present enough details to be convincing. However, be careful not to overwhelm

your reader with a level of detail that obscures your main objective of securing funding. The proposal is not intended to provide enough information for your work to be duplicated.

Homework

1. Using your presentation materials from EXERCISE 9.3, draft a research design and methods sections for your proposal.
2. Seek comments on your written work. To help those giving you feedback, you may even suggest a list of questions, such as "Is the description of how I will sample clear?" and "Do you understand what I plan to do with the data?"
3. Revise your research design and methods sections based on the comments of your colleagues.

CHAPTER 10

Plan for Expected and Unexpected Results

> If your approach fails to achieve the expected outcome, what will you do? Showing that you've thought about it gives reviewers confidence in the proposal.
>
> —Jill Mikucki, University of Tennessee–Knoxville

Strong scientific research proposals include a section that describes expected results and explicitly discusses interpretation of these expected results. However, despite the most careful planning, you might encounter obstacles during implementation or produce unexpected results that require you to rethink original concepts, redesign experiments, add new protocols, or eliminate parts of the original protocols.

In our surveys of colleagues, we were impressed by the emphasis they placed on the importance of considering both likely and unlikely outcomes. Investigators who are prepared to rapidly redirect research, or who are able to respond quickly to unusual yet important results, often produce

the most exciting results. Science is filled with dramatic examples of major breakthroughs coming serendipitously through failed experiments or as by-products of unrelated projects. Therefore, we recommend that you also discuss unexpected or unlikely outcomes along with expected results.

In this chapter, we offer a few ways to address both expected and unexpected results in your proposal. We also use this opportunity to revisit the idea of "broader impacts," previously discussed in Chapter 6.

Placement in the Proposal

There is no consensus from authors and reviewers about where expected results and broader impacts should be located within the proposal. Some writers discuss their anticipated results throughout the methods and hypotheses sections, while others place the discussion near the end of the body of the proposal. Looking back at the suggested order of presentation of the project description from Chapter 3, you'll see that we included "expected results" in the section on the research plan. You may choose to locate the discussion of expected results there, or you might develop a stand-alone section to discuss results. We recommend discussing them in the research plan section; your discussion can flow logically from objectives, hypotheses, and methods to analysis and then expected results. This organizational structure, with

clearly identified sections, will keep your reviewers focused. We also recommend presenting the broader impacts in a stand-alone section at the end of the project description.

IV. Project Description
  A. Results from prior agency support (Chapter 8)
  B. Statement of the problem and significance (Chapter 4)
  C. Introduction and background (Chapter 8)
    - Relevant literature review
    - Preliminary data
    - Conceptual, empirical, or quantitative model
    - Justification of approach or novel methods
  D. Research plan (Chapter 9)
    - Overview of research design
    - Objectives or specific aims, hypotheses, and methods (Chapters 7 and 9)
    - Analysis and expected results (Chapter 9 and this chapter)
    - Timetable (Chapter 11)
  E. Broader impacts (this chapter and Chapter 6)

Sample titles for sections that discuss expected and unexpected outcomes include:

- Expected Results and Their Broader Significance
- Future Directions
- Related Research
- Model Limitation and Potentials
- Model Verifications

For an NSF proposal, the section on broader impacts must be titled "Broader Impacts." For other agencies, you may be able to choose a different title for your broader impacts section. Typically, the broader impacts section is placed at the end of the proposal after a discussion of scientific results and before the reference list. The section on broader impacts should contain subsections with additional titles to help funnel and focus the reader. Sample titles for sections that discuss broader impacts include:

- Broader Collaborations and Scientific Impact
- Synergy and Overarching Synthesis
- Outreach and Education
- Students, Interns, and Early Career Scientists
- Women and Minorities

We will discuss the content of possible subsections later in this chapter.

Explicitly Addressing Outcomes

Careful consideration of expected outcomes underlies scientific competency and shows that the proposal authors are well prepared. Often the outcome of a project or experiment is fairly predictable. This does not mean that the research is stale or boring but may simply indicate that

"PLANNING FOR UNEXPECTED OUTCOMES FEELS LIKE ENABLING FAILURE."

the authors effectively established hypotheses and models, examined the literature for applicable results from other systems, and perhaps were just a bit lucky. Sometimes the outcomes are not predictable; it is crucial to be prepared for this possibility.

There are many ways to explicitly address potential outcomes in your proposal. Here are several approaches:

- Provide diagrams of the approaches you plan to use to achieve different outcomes. If everything you propose depends on one specific outcome and that outcome does not occur, then the research will be considered very risky. No research is risk-free, and risky research sometimes yields a highly productive result. However, if you can outline interesting pathways that alternative

outcomes might take, your research will be more likely to succeed. Make it clear that each potential pathway can lead to valuable and interesting results.

- Construct a simulation model to predict likely outcomes. (Refer back to Chapter 8 for more discussion on models.)
- Graphically depict the relationships you expect to see as a result of your work, and discuss your analysis and interpretation. Be sure to briefly discuss the interpretation that you will make if the patterns do not come out as predicted. State what such unexpected outcomes would mean for your overall goal. In many cases, writers include fairly detailed descriptions of the analysis necessary to interpret the results. Attention to analysis can be especially important when the analysis is novel, difficult, quirky, or somewhat controversial.
- Estimate the likelihood that your work might present an unexpected outcome. It is worth anticipating unlikely events or results because reviewers from different perspectives or disciplines may consider issues that you do not. By considering alternatives, you may be able to identify aspects of your research that require special explanation for a broad audience. Some proposals include a table with alternative hypotheses or outcomes. In certain cases, it is possible that an

alternative is highly implausible because it would require a mechanism that defies all logic. You may need little explanation for such an unlikely outcome. A case in which two mechanisms are nearly equally plausible will require more discussion.

Given other constraints on your proposal, your discussion of expected and unexpected results will probably be restricted to a few paragraphs or figures. The extent to which you need to discuss this topic depends in part on the ramifications of the different outcomes to your research design, hypotheses, and broader goals.

What Is a Broader Impact?

The NSF PAPPG states that the project description must include a separate section titled "Broader Impacts." Without a clearly executed section on broader impacts, the proposal could be returned to you without review. But even when proposing projects to other agencies or when writing a dissertation proposal, it is still important to present the broader impacts of your work. In fact, this strategy recently proved successful for one of us who submitted a proposal to an agency that doesn't provide specific guidelines on what to include in a proposal. The managing program officer told us that the inclusion of the broader impacts of our intended

work really impressed the reviewers and played a significant role in the successful funding of our proposal.

What is a broader impact? In a general sense, it is another type of result that you will generate, in addition to the scientific results. Recall that you have a section within the project summary dedicated to highlighting the broader impacts of your research; the section within the project description should expand on that summary paragraph.

Broader impacts cover a wide range of activities and results. Here are some examples.

- *Outreach*. Anytime you engage with people outside the scientific research community to convey your science to them, you are conducting outreach. Giving public lectures and interacting with the media are common examples.

- *Education*. As with outreach, anytime you engage with students of any age group to convey your science to them, you are making a broader impact. In addition to incorporating your research into courses that you teach, you may also visit elementary school classrooms or host field trips to your lab or field site. Other examples are hosting an undergraduate summer intern or working with local high-school teachers to develop their curricula.

- *Synergistic activities.* A collaboration in which your data or results are shared with another scientist or group of scientists in a different field to improve or enhance their results is a broader impact. Examples include contributing your results to enhance the performance of another researcher's scientific model or contributing to the overarching synthesis of data for a particular system or geographic region.
- *Diversity.* Increasing the participation of women, persons with disabilities, and underrepresented minorities in scientific research is of utmost importance to most agencies and universities. Be sure to note the numbers of female and underrepresented minority students, postdocs, and early-career researchers working on your project.
- *Data availability.* As we noted in the discussion of data management in Chapter 2, many funding agencies require researchers to make data available to the public within a certain timeframe. If you will be making data available immediately or contributing to an important database that is used widely, you should note it in your broader impacts section.
- *Public impact.* You have probably discussed the broader scientific impact of your work in your significance

section. You can revisit that discussion in this broader impacts section with an emphasis on the impact of your work on humanity or on the environment. If your work will also assist with policy development or management decisions for a sensitive area, ecosystem, or species, this is a good place to mention it.

As with all other sections, you have limited space to present the broader impacts. We recommend keeping this section to a page or less and starting with the wider-reaching impacts, such as those that affect the general public, and then funneling to the more focused activities, such as those involving students.

Key Points

1. In discussing the results of your research, it is important to address both expected and unexpected outcomes. Even outcomes that seem far-fetched or illogical deserve mention, but they require less explanation.
2. The description and explanation of potential outcomes can be included in the methods section or put in a stand-alone section. In either case, you will have limited space. Use graphs, diagrams, or models to help illustrate the various possibilities.

3. A broader impacts section should note activities and results that range beyond your scientific results. You should describe ways in which your research affects the general public, as well as outreach, education, synergies, diversity, and data availability.

Homework

1. Starting with the methods section you crafted as part of the homework in Chapter 9, develop a list of outcomes you expect to achieve from the work. Look closely again at your methods section and think about the possible unexpected outcomes that might happen. Refer back to your literature review to see if other relevant or similar studies describe potential results that you haven't considered.
2. Construct a visual depiction of the approaches you plan to use and the resulting relationships—you may find that you need more than one visual aid to clearly and fully depict the possible outcomes of your work.
3. Using the examples provided in this chapter, list and briefly describe all the broader impacts that will result from your project. You can then use this list to develop your broader impacts section.

CHAPTER 11

A Reality Check with the Timeline and Project Management Plan

> A simple visual guide, such as a Gantt chart, shows the reviewer what you are planning to do, that you have thought about your research in detail, and, if it is done well, it can serve as a great, convincing overview of the project.
>
> —Jonathan O'Donnell, Research Grant Development, RMIT University, Australia

An organized and simple timeline is useful to both author and reviewer. Devising a timeline helps you, the author, acquire an appreciation for the links between tasks and the time required for each part of the study. It also provides insight into the resources, such as money and labor, that you will require to complete the proposed project.

A well-conceived timeline demonstrates to reviewers that you have carefully assessed the personnel and financial commitments required for your project. A realistic timeline shows that the project is feasible, and builds confidence in your judgment. If reviewers find the timeline overly

optimistic, they may have doubts about funding the proposal. Thinking carefully about your timeline can also help to avoid many future problems. For example, at the completion of a grant cycle, you may decide to apply for funds to carry out the next steps of your work. Your new proposal will be reviewed more favorably if the time and budget estimates for your first proposal were accurate. If you significantly underestimated or overestimated the time or budget needed to complete the original project, you will be in the undesirable position of having to justify yourself in the new application.

Many people do not construct the formal timeline for a project until after they have written most other sections of the proposal. However, you should begin to think seriously about the time required for specific tasks as you develop your research plan. In this chapter, we discuss the elements of timelines and provide examples of different ways to present your timeline in your proposal. We also discuss the concept of project management plans, which are required in some solicitations as supplemental documents.

Constructing a Timeline

In proposals formatted for agencies such as NSF, the timeline usually appears at the end of the project description (discussed in Chapters 4, 7–10), just before the references. There is no required format for a timeline, but the major

milestones and durations of tasks within the project are usually depicted in chronological order. Some authors simply list the general tasks and target dates, while others use more elaborate schematics. A common schematic is the Gantt chart, a bar chart used specifically for project schedules. In general, the timeline should fit on a single page. If justification or explanation of specific requirements for particular tasks is needed, it should be included in an accompanying paragraph.

A timeline will include many different types of information. Some examples are:

- The beginning and end of each field season or experimental period
- The time needed to construct an instrument, purchase new equipment, or develop a novel technique
- The time needed to create a genetic library, grow particular cultures, etc.
- The time scheduled to use equipment at other facilities (e.g., telescope time, use of a mass spectrophotometer, sample deep-sea squid, etc.)
- Starting and completion dates for a monitoring program
- The time needed for analysis of data

- The time needed for writing publications
- Expected dates for publication of results

No matter how carefully you plan your timeline, at some point your plans and reality will meet. All of us, even veteran researchers, can underestimate the time required for different tasks. If you are unsure, make your best estimate and then double it. This still may not be enough time, but it may put you in the ballpark. And remember, scientists with experience conducting the same type of research as you propose are your best sources of assistance in this area. Be sure, too, to construct your timeline so that it fits within the overall time period of the grant cycle for the solicitation. For example, if you're applying for a three-year grant, your timeline must fit within three years.

Here are three examples showing different ways to present your project timeline. As you consider each one, think about which format will work best for your own project. Examples 1 and 2 present the same study in different formats.

Example 1. *A Simple Timeline for a Fictional One-Year Study on Amphibian Density and Respiration*

JUNE 2019

- Order equipment.
- Receive, test, and calibrate equipment.
- Choose sites and test-sampling methods.
- Install temperature-monitoring stations.

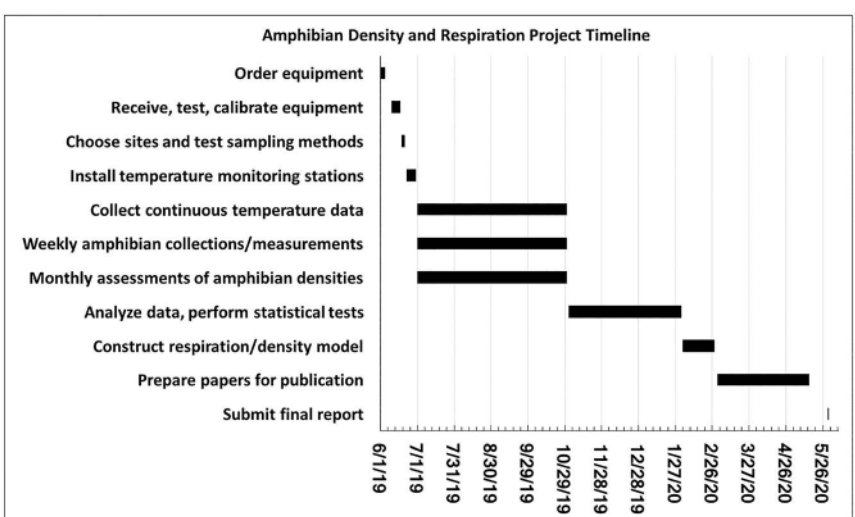
JULY–OCTOBER 2019

- Collect continuous temperature data.
- Make weekly amphibian collections and measurements.
- Make monthly assessments of amphibian densities.

NOVEMBER 2019–MAY 2020

- Analyze data, perform statistical tests.
- Construct respiration/density model.
- Prepare papers for publication.
- Submit final report.

Example 2. *A Gantt Chart for a Fictional One-Year Study on Amphibian Density and Respiration*



Example 3. *A Timetable for a Four-Year Study on Extracellular and Intracellular Signals Regulation Cell Division and Differentiation*

Projected Timetable	Year 1	Year 2	Year 3	Year 4
Cloning of *pex*-1	xxx	—	—	—
Molecular investigations of *pex*-1 function	—	xxx	xxx	xxx
Genetic characterization of *pex*-1	xx	xx	xx	xx
Studies of spatial regulation of RAS-MAPK activity	—	xx	xx	xx
Screening for pachytene exit mutants	xxx	xxx	xx	x
Screening for suppressors/ enhancers of RAS-MAPK	x	xx	xxx	xxx
Characterization of newly identified *pex* genes	x	xx	xx	xxx
Dissection of cellular regulation of pachytene exit	xxx	x	—	—
Examination of PKA and cdc2 roles in pachytene exit	xx	xxx	xx	xx
RAS-MAPK and mitogenic signaling	xx	xx	xx	—
Investigation of the UCN fate	x	xx	x	—

— = done or not begun; x = low effort; xx = moderate effort; xxx = high effort
Source: E. Lambie, Dartmouth College.

No matter the format you choose for your timeline, be sure that the information is clear, concise, and complete. In addition, check to make sure that your timeline illustrates

how the project activities will flow as well as how they are connected to one another and whether they realistically fit within the grant cycle timeframe.

Developing a Full Project Management Plan

Some solicitations require a full project management plan as a supplemental document, especially if the project is very expensive or complex. If it is not required, you do not need to develop a full project management plan to submit with your proposal, but you should consider doing it anyway, especially if your project is very complex, since it will help you to manage all the various aspects of the schedule and budget. Examples of complex projects might be the purchase, construction, and installation of a large and costly instrument or a computer data center, and a multifaceted field campaign that involves several teams from different universities. A project management plan is a cohesive set of individual management plans for a range of components, including cost, scope, schedule, risk, communications, staff, subcontracts, and more.

If the solicitation requires a full project management plan, it will likely state which components are to be included. You can find standard templates and outlines for project management plans by searching on the internet. A Google image search for "project management plan

template" produces a variety of samples showing various common types of content and formatting styles. Project management plans, which have been used for a long time in such disciplines as business and engineering, have only recently come into use for scientific research projects. Thus, many examples and templates you find will be intended for other fields, and you may find that you will need to modify them or omit sections that aren't relevant to the management of your research project.

Some of the most common components of a project management plan are listed here:

- *Organizational chart*. Include all of the people involved in the project, as well as their roles and their relationships to each other.

- *Cost management plan*. Using the project budget, describe how you will track and manage spending during the course of the project.

- *Scope management plan*. The scope encompasses all the tasks and subtasks of your project. Provide a summary describing how you will maintain focus to ensure that all tasks are completed and how you will avoid adding extra tasks (scope creep).

- *Schedule management plan*. To compile this plan, you will need to expand beyond a basic timeline into a

more detailed schedule that accounts for all milestones, tasks, and subtasks, as well as the resources needed to complete them. A Gantt chart with sections for tasks and subtasks is the most effective way to depict a schedule for complex, multifaceted projects. Include a description of how you will keep the schedule on track.

- *Risk analysis and management plan*. All projects have risks. Develop a list of risks (typically called a risk register) and assess their likelihood. Describe how you will decrease the possibility of each risk occurring or how you will manage it if it happens.

- *Communications plan*. List all project meetings, updates, and other types of communication that will occur, as well as how often they will occur and what information will be included. Include the names or positions of the people who will be included in each communication.

- *Change management plan*. Sometimes plans change. Describe how changes to the project scope, budget, and schedule will be managed and approved.

- *Procurement (contracts) management plan*. If your project involves subcontracts, include a description of your contracting process.

Key Points

1. A well-conceived timeline shows the feasibility of your project and demonstrates to reviewers that you have carefully assessed the time, personnel, and financial commitments required for the project.
2. Typically, the timeline appears at the end of the project description just before the references and includes the major milestones and durations of tasks in chronological order. There are various ways to depict the timeline, ranging from a simple list of general tasks and target dates to more elaborate schematics.
3. Some solicitations now require a full project management plan as a supplemental document. A project management plan is a cohesive set of individual management plans covering cost, scope, schedule, risk, communications, staff, subcontracts, and other aspects of the project.

Homework

1. Determine how you want to present your timeline in your proposal. If there is a standard format typically used in your field, it is a good idea to stick with it; if you don't know, consult colleagues and the sample proposals you've been reviewing.

2. Start with your overall grant cycle time period, such as three or five years, and outline major milestones for your research project, including start date, end date, known experimental or fieldwork periods, time for analysis, time for writing, dates for publication submittals, and so on.
3. Refer back to the research plan and methods section you developed as part of the homework in Chapter 9 and list all the associated tasks in chronological order. Estimate the length of time for each task.
4. Using your outline of major milestones, fill in the time periods between each milestone with the applicable tasks and associated time spans.

CHAPTER 12

References in Detail: How Many and How Recent?

> Your citations reflect your knowledge of the literature and where your work fits within the field. As a reviewer, I want to see that you know the state of the art, how your work is related to it, and how your proposal will advance it!
>
> —James Kinsey, Department of Applied Ocean Physics and Engineering, Woods Hole Oceanographic Institution

Properly cited and appropriate references are essential to a strong proposal. References alone will not determine whether a proposal is funded, but the weak or incorrect use of citations suggests insufficient preparation and can undermine a reviewer's confidence in an otherwise strong application. Citations convey critical information with a minimum of words.

Inexperienced writers sometimes have difficulty knowing how to correctly cite references, how often and where to position references, and how to select among many possible choices. This chapter provides guidelines for the judicious

use of citations in a proposal and describes some of the more common referencing problems.

Reference Basics

Which references should I cite? This is a fundamental question for authors of research proposals and manuscripts. The selections you make indicate a great deal about your perspective and knowledge of the current state of your field. (This is also discussed in Chapter 8 in relation to your literature review.) It is advisable to cite papers that are well known for their importance to your specific topic. References addressing your system directly and perhaps even your specific research question should also be used. We again emphasize the importance of being unbiased: cite papers that dispute your position and directly discuss the key differences in opinion. You should probably rely most heavily on recent papers, although in certain cases an older paper may still be considered the seminal reference. In general, most cited papers will be less than ten years old. Inclusion of extremely recent references lends freshness to your application. It also demonstrates that you keep current with the literature.

The conventions for citations in manuscripts also hold for proposals. Here are some examples of these conventions:

- Cite peer-reviewed works whenever possible.
- Use non-reviewed work, reports, unpublished data, and personal communications sparingly.
- Cite your own work, but not excessively.

Reviewers always consider whether your proposal contains the most appropriate and consequential references. Consider who is likely to review your proposal, and be sure to reference their work when it is relevant to your proposal. (See Chapters 1 and 3 for more on who will likely review your proposal.)

Finally, cite only papers that you have actually read. Occasionally writers lift lists of references from other papers. The citations may not be relevant, however, in even a slightly altered context. When reviewers see that your list contains irrelevant references, they will question the validity and integrity of your work.

How many references should I include? You may have heard this vague rule of thumb: "You don't want more than you need, but be sure to have enough." In general, cite all papers that are essential to establishing credibility or feasibility, but limit the use of citations that simply provide background and support. When establishing background, include the few most important or influential papers. Lists of more than five papers following a statement are rarely

necessary. Do not use multiple references if one will suffice. Including numerous citations for facts that are well known and commonly accepted in your discipline will suggest that you are inexperienced.

All citations should be accurate. Your references must be correct—pay particular attention to the date of publication. One of us was chastised in a review for several text references that did not match the full citation at the end of the paper. Although it was only a matter of a publication year not being identical in both places, this discrepancy gave a poor impression. As one reviewer pointed out, references are the only information that can be checked to determine whether authors are likely to be careful and precise. If a mistake in the citations is representative of the care the authors would give to their research, it might not be scrupulously done. This judgment may seem harsh, but it reflects the strong negative response of many scientists to perceived sloppiness.

If you are unsure how to correctly cite a particular reference, check *The Chicago Manual of Style,* widely used in academic publishing, or the Council of Science Editors' *Scientific Style and Format*. Citing sources from the internet, databases, maps, or illustrations can be tricky. Be careful, in any case, to give credit appropriately when you reproduce copyrighted material. Get explicit permission if it is required.

Common Problems

Below are simple examples that illustrate how placement and number of references can lead to ambiguities. All references are fictional.

Too Many References, Vague References

> Air pollution affects plants in a variety of ways (Browner and Bowles 1994; Kramer and Berger 2001; Smith and White 2003; Pearce and Omer 1999; McPhee et al. 2006).

This is a vague statement to begin with, which makes it difficult to reference. It is not clear what the references in this list are supposed to indicate. If you use such open-ended statements, select only one or two general reviews for support. "Air pollution affects plants in a variety of ways (e.g., Smith and White 2003)." This suggests that Smith and White is a review paper that discusses the many ways in which air pollution affects plants. If Smith and White present only one way in which air pollution affects plants, it is inappropriate to reference the statement this way.

References Placed Poorly in the Text

Sometimes authors place all references at the end of a paragraph when references may refer to different clauses within the paragraph. This can be very confusing and dilute the impact of the references. Compare the placement of references in these two examples:

> *Example 1.* While studies of the effects of vines on riparian plants have been conducted, there has not been an integrated analysis of the effect of vines on riparian plants (Asanti and Laszlo 1991; Schwartz et al. 2004; Jones and Smith 2005; Fullington 1977).
>
> *Example 2.* While studies of the effects of vines on plants in deltas (Asanti and Laszlo 1991; Fullington 1977) and estuaries (Schwartz et al. 2004; Jones and Smith 2005) have been conducted, there has not been an integrated analysis of the effect of vines on riparian plants.

Example 1 suggests that four studies identified a need for an integrated analysis of the effects of vines on riparian vegetation. In Example 2, specific studies in deltas and estuaries are cited. The absence of a reference at the end of the sentence indicates that no one prior to the author has identified the lack of an integrated analysis of vines on riparian plants.

Weak or Incorrect References

Including a paper in your references says that you have read the paper and understand it thoroughly. Cite it carefully, since its authors (who may end up reviewing your proposal) will be perturbed if their work is referenced incorrectly.

Ambiguous Reference Notations

Do not confuse references that are examples of your points with ones that support your argument in some other

way or make a similar point to the one you are making. Keep in mind the meanings of common Latin abbreviations and use them accordingly.

- The abbreviation "e.g." stands for *exempli gratia* and means "such as" or "for example."
- The abbreviation "i.e." stands for *id est* and means "that is."
- The abbreviation "cf." is derived from the Latin verb *conferre* and means "confer" or "compare."
- The abbreviation "etc." stands for *et cetera* and means "and other things" or "and so forth."
- The abbreviation "et al." stands for *et alia* and is used to mean "and others," particularly when citing names.

Exercises for Writing References

Before beginning these exercises, check the citation format required by the agency to which you are applying.

EXERCISE 12.1. Begin developing a library of references for your proposal using a commercial software package. Check with colleagues to see which software they use. It will serve you not only for this proposal but for all proposals and papers you write in the future. It is not uncommon for re-

"THE ONLINE DIRECTORY SAYS IT SHOULD BE RIGHT HERE IN THIS ANTIQUE REFERENCE LIBRARY."

searchers to build reference libraries containing thousands of articles over their careers.

EXERCISE 12.2. Here is a simple drill: Read a paragraph written by a colleague or classmate in a field that is unfamiliar to you. You can also use text from one of the example proposals you've been reviewing. Examine each reference and speculate on why it is there and what it should be telling you. Check with the author or check the sources against the text to see whether the intended message was correctly interpreted. This exercise is most effective when you are not familiar with the references cited. In a follow-up exercise, apply the same consideration to your own citations.

Key Points

1. Appropriately chosen and properly cited references are essential to a strong proposal. You should cite papers that are well known for their importance to a specific topic as well as references that directly address your system or even your specific research question.
2. References alone will not determine whether a proposal is funded, but the weak use of citations will suggest insufficient preparation and undermine a reader's confidence in an otherwise good application.
3. Avoid common problems such as citing too many or too few references and placing references poorly within the text. Also make sure references are both accurate in terms of what they're conveying and correct in source details so the reviewer can easily find them.

Homework

1. If you do not already have a reference library built using a common software package (e.g. EndNote, JabRef), start one. Talk to your colleagues about which software they prefer. There are many programs available, and some are free.
2. Using the components of your project description that you have already created in previous homework

assignments (significance section, literature review, introduction and background sections, research plan and methods, etc.), enter all the references you cited into your reference library.

3. Review your project description to determine if you are missing any references and add them.
4. In your reference library software, you should now be able to select all the references you've cited in your proposal and have the program automatically build a reference list to include with your submission.

CHAPTER 13

Preparing a Budget

> The budget narrative should make a persuasive case for investing in you and your team. It should answer all the questions a skeptical reviewer would ask by explaining how your costs were determined, what each person will do, why equipment is needed, and how it will be used.
>
> —Celia Mathews Elliott, Department of Physics, University of Illinois at Urbana-Champaign

Most scientists write their budgets last. The basic principles of budget preparation remain the same whether you are applying to a government agency for $500,000 or to your department's graduate student fund for $5,000. Budget writing requires careful planning and detailed knowledge of time and salary requirements as well as indirect costs, which include institutional, administrative, and overhead costs. It also requires fairly precise cost estimates for equipment, supplies, field expenses, and anticipated travel.

Your most important consideration when preparing your budget should be the ethics involved in accepting

financial support for scientific research and how you will spend the money. You will be obliged to follow the terms of the award and to take full responsibility for the veracity of your data and the appropriate use of the research dollars. For ethical and practical reasons, then, you should include only costs that relate directly to your research, and you should provide your most accurate estimate of the overall cost of conducting the research. Although some agencies are flexible and allow award costs to be transferred among categories as the research progresses, others are much stricter. In either case, the more prepared you are to follow your original budget when spending funds, the better off you will be in terms of accomplishing all of your goals with the allotted dollars.

In this chapter, we cover the typical components of a proposal budget and budget narrative (also called the budget justification), and we provide a sample budget template. We also discuss considerations and strategies for estimating, cost sharing, and negotiating.

What Should a Budget Include?

Preparing a budget gets easier with experience. All federal agencies, and most other funding organizations, have a template for formally itemizing the budget into categories. These organizations often provide detailed guidelines for particular costs. If you do not understand a cost that is listed

in the guidelines, discuss it with both your own institution's grants office and the program director at the funding agency.

Here are a few of the most common budget categories.

Salaries. It is expensive to pay people, and research is labor intensive. Funding for principal investigators is typically limited to anywhere from half a month to two months of summer salary for each year of work the proposal covers. Some programs have salary caps, and some programs do not allow PI salaries. Salaries of other research staff are calculated according to the number of calendar months per year you indicate, which will depend on the percentage of a person's time that will be devoted to the project. Graduate stipends and undergraduate salaries are also typically included. Each salary listed also carries additional associated costs to cover benefits, referred to as fringe benefits. This is known as the fully burdened salary rate. Because there are many regulations regarding salaries and benefits, always rely on your institutional grant management experts to help determine the correct rates. Also, in multiyear proposals, don't forget to account for cost-of-living adjustments, performance raises, and promotions.

Equipment. Most institutions and agencies have specific definitions of equipment (e.g., items that cost more than $5,000 and will last more than one year). It is appropriate to include in your proposal equipment that is necessary to conduct the proposed work. However, the need for pro-

hibitively expensive equipment may limit your proposal's success. Any significant equipment expenditures should be discussed in advance with the program officer at the funding agency to determine their suitability. For large purchases, institutions and agencies will sometimes enter into "cost sharing" agreements, with both parties combining funds to purchase equipment. These arrangements must be finalized prior to submission of the proposal, and they require time to negotiate; plan in advance if you wish to explore cost-sharing agreements.

Supplies. Include all expendable items, including lab ware, chemicals and reagents, field utensils, and minor computer accessories necessary for the successful completion of your project.

Travel. Include destinations, number of trips, mileage, lodging, and a per diem for food. Justify all travel destinations (e.g., field sites, meetings with collaborators, conferences, outreach, patient reviews, and so on). Obtain your institutional guidelines for costs related to travel. Many institutions use the standard government rates for per diem costs, lodging, and mileage set forth annually by the General Services Administration. It is common to include travel costs for presenting results of the study in later years of a project, but each agency will have its own rules and restrictions.

Miscellaneous expenses. These expenses may include such things as computer time or courier services for rapid

delivery of time- or temperature-sensitive samples. These are not part of the institutional costs to be covered by the indirect cost fee. Discuss these items with other people in your department and your grants office to determine rules and common practices.

Subcontracts. This category applies when you plan to pay for work conducted at another institution or a company. Again, institutional regulations will apply.

Indirect costs. An indirect cost, also known as overhead, is a cost not directly accountable to your project but paid to your institution as part of the grant budget. Examples of indirect costs include administration (payroll or purchasing office) or facility operations (electricity used to light your office and lab). Indirect costs on your proposal are determined using a rate already negotiated by your institution with the funding agency to which you're applying. Your campus grants officer can tell you which indirect rate you will need to use. Typically, it is a percentage of your total budget that is added to the bottom line. Keep in mind that most campuses charge different overhead rates for different types of research activities (e.g., off-campus versus on-campus activities). In addition, most funding agencies restrict the overhead allowed on large equipment purchases and subcontracts. All this information is available to you in precise guidelines from your institution's grants office.

The Budget Narrative

It is often necessary to append a page to the budget in which you justify your budgetary requests. NSF and other large agencies certainly require this. The budget narrative (or justification) page might explain why you need four thousand test tubes or sixteen trips to your field site during one field season. A simple way to format the budget narrative is to use the same subheadings listed on your budget worksheet and provide a paragraph under each subheading that describes the need for the requested dollars and how you calculated it.

Submitting Your Budget

Most federal agencies require proposal budgets to be submitted through Grants.gov, though NSF still allows them to be submitted through FastLane. Whether the budget should be submitted by your grants office or directly by you depends on your institution's policies and practices. Make sure to ask your sponsored programs office about the budget submission process early and make note of any internal deadlines.

Finalizing a budget and preparing it for submission to the funding agency can be complicated and time consuming. Most agencies require a page bearing your signature

and the signature of the individual at your institution responsible for oversight of the funds. You may also have to obtain the signatures of your department chair, dean, and provost before the institutional representative will sign your budget page.

Cost Sharing and Negotiating

Funding agencies sometimes seek matching funds or cost sharing from the investigator's institution. Examples of cost sharing include graduate student stipends, equipment purchases, or undergraduate internships. Cost sharing can often demonstrate institutional support for a particular proposal, and it can benefit others at the institution beyond those directly involved in the proposed project.

Your program officer may seek to negotiate a reduced budget and thus a reduced scope of work. Program officers at federal agencies have limited budgets and aim to fund as much of the best science as they possibly can. You are more likely to face a negotiation for a reduced budget and scope if your proposal does well in review and has a novel approach to an important science question but your program officer doesn't have the means to fully fund you. This is becoming increasingly common, so keep this possibility in mind as you prepare your budget; if you are asked to reduce your

budget, have some ideas ready for dividing the work into separate phases or tackling only some of your specific aims or objectives.

Final Thoughts on Preparing Budgets

Most scientists carefully estimate the true costs they expect to encounter while conducting research, and they submit a budget based on those realistic estimates. We strongly advise adopting this strategy. However, it is easy for those early in their careers to under- or overestimate the amount of work involved and, consequently, to under- or overestimate the amount of money needed. Caution, care, and consultation with senior colleagues or advisors are important. Not only will preparing a fair budget make your proposal more competitive, but it is the ethically appropriate strategy.

Shown here is a sample budget for a three-year grant, a typical award period at NSF and other agencies. Note that annual salary increases are built in for the PI, postdoc, and laboratory technician, since these are typically full-time permanent staff. Graduate students are paid a fixed stipend, which may or may not change over time. It is a good idea to confirm with your department administrator whether graduate student stipends in your department will remain fixed over the duration of your grant.

Sample Budget for Field and Lab Study (in dollars)

	Itemization		
	Year 1	Year 2	Year 3
Principal investigator, 1 month summer salary	9,500	9,975	10,474
Fringe benefits @ 40%	3,800	3,990	4,190
Postdoctoral research associate, full-time	48,000	50,400	52,920
Fringe benefits @ 35%	16,800	17,640	18,522
Graduate research assistant, full-time	24,000	24,000	24,000
Fringe benefits @ 15%	3,600	3,600	3,600
Part-time laboratory technician, 12 hours per week	7,488	7,862	8,255
Fringe benefits @ 10%	748	786	826
Summer field and lab assistant, 40 hours per week for 10 weeks	4,800	4,800	4,800
Fringe benefits @ 10%	480	480	480
Travel total	2,350	2,350	2,350
10 trips to field site (100 miles round trip at $0.55/mile)	550	550	0
Attend one conference	1,800	1,800	1,800
Supplies total	2,500	2,500	1,400
Reagents	400	400	
Field sampling bottles, bags, and tools	700	700	
Laboratory chemicals and containers	800	800	800
Analytical chemicals	600	600	600
Publication costs	0	1,500	1,500
Equipment	0	0	0
Total direct costs	124,066	129,883	133,317
Indirect cost @ 50%	62,033	64,942	66,659
Total budget	186,099	194,825	199,976
Cumulative Budget for Years 1, 2, 3			580,899

Key Points

1. Careful planning and detailed knowledge of time and cost information for your project will lead to the most precise estimate. Ethically, you are responsible for appropriately using the dollars you accept with your award.
2. Your budget should contain all costs required to complete the work you propose, including salaries, travel, equipment, supplies, subcontracts, and indirect costs.
3. Cost sharing or negotiating a reduced budget—or both—can benefit you, your organization, and the funding agency by helping to advance your research even when full funds aren't available.

Homework

1. Before developing your budget, gather necessary information such as indirect cost rates, expected salary rates and expected increases, price quotes for special equipment, and estimates for costs of planned travel.
2. Using the timeline you developed as part of the homework for Chapter 11, calculate the salary amounts required for the proposed work. Don't forget to include

fringe benefit costs and expected salary increases in future years.

3. Using all the information you've gathered, construct your annual budgets as well as your cumulative (all-years) budget.

CHAPTER 14

Submitting and Tracking Your Proposal

> It is perfectly acceptable to write a polite email or ask at a meeting when decisions might be made, but always be respectful of the program officer. Think of the program officer as you would your grandmother who might leave you an inheritance someday. You want to build a relationship through interactions with her, but you wouldn't be pushy or negative or pester her.
>
> —William G. Ambrose, Biology Department, Bates College

If you have finished your proposal, congratulations! You have checked it for errors, typos, grammar, and proper formatting and made certain that you followed the guidelines and rules of your institution and the funding agency.

In this chapter, we offer some final considerations as you begin the process of submitting your proposal. We also explore what happens to your proposal after you submit it.

Final Considerations for Submission

At this point, you should be feeling excited and relieved. You are probably also exhausted. To get through the last few tasks, consider some final points.

Know the online system you're using. Nowadays, submissions are almost exclusively done electronically. However, we strongly advise you not to wait until the last minute to start the online process, especially if this is your first time using a particular electronic gateway. By now, you should have examined the guidelines for electronic submission. Investigators applying for awards from NSF use FastLane for submitting their proposals, and those who receive awards use it for ancillary activities such as submitting annual reports, revising budgets, and submitting supplements. For all other federal government agencies, the portal Grants.gov is the primary gateway between an institution and the agency. Collaboration with multiple investigators is relatively convenient with an online system, which allows one investigator to upload a draft of a document and collaborators to access and modify it. Ask colleagues and the grants management or sponsored programs officer of your institution for other tips about electronic submissions. With electronic submissions, your sponsored programs or grants management officer will submit the actual electronic document and will receive acknowledgment that the document has been successfully transmitted.

Consider including a cover letter. Although not all agencies require a cover letter, we suggest that you consider writing one. FastLane and Grants.gov allow submission of additional material, and, depending on the circumstances, a cover letter could be useful. In the letter you may describe the importance of the work, help categorize it if it is in a hard-to-identify area, or discuss any dealings you may have had with the program director.

Suggest potential reviewers. Online submittal systems typically have a place to enter the names of potential reviewers. If not, you may wish to list suitable reviewers in your cover letter. Keep in mind that none of these people should be collaborators nor anyone with whom you have recently published a paper, your advisors, or your advisees. In some cases, it may be necessary to include the name of a reviewer to avoid if you have a specific reason (such as a major conflict of interest); this information should be held confidential by the agency. However, use the option sparingly. Most scientists never need to name reviewers to avoid.

What Happens to Your Proposal After You Submit It?

Until the advent of electronic submissions, all proposals were received in the mailroom of the funding agency. Tens, hundreds, or even thousands of submissions may have been

received within a short time period. Regardless of how a proposal is received today, each proposal is assigned a tracking number. When Grants.gov is the submission gateway, the system immediately generates a tracking number for the proposal. The tracking number is also provided in the application submission confirmation email, which is sent to the "authorized organizational representative," usually someone in your institution's grants office. After validation by Grants.gov, the proposal is forwarded to the designated federal agency, where it is assigned an agency-specific tracking number. If your proposal is successful, this number will become the award number.

After a proposal is processed it will usually be sent to one or more individuals for review. Some agencies or private foundations conduct in-house reviews. It is more common for the person responsible for evaluating grant proposals and making awards to assemble a list of ad hoc reviewers who then provide written reviews of your proposal. Ad hoc reviewers have no formal association with the funding agency; they are members of the research community, considered to be your peers, who agree to review a proposal. Their function is similar to that of the ad hoc reviewers of manuscripts submitted to journals. Ad hoc reviewers are found in a variety of ways, including from your citation section, your recommendations, your cover letter, past contacts with the agency, and general standing in the field.

Once the ad hoc reviews are completed, staff in the funding program typically arrange for the ad hoc reviews of many proposals to be evaluated by a panel consisting, again, of peer scientists (often leaders in their fields, some of whom have received funds from that agency in the past), as well as members of the agency staff. For some U.S. federal agencies, several panel members read each proposal and write reviews that are added to the reviews submitted by ad hoc reviewers. Sometimes a single panel member may be identified as the primary reader to present the major ideas of your proposal to the rest of the panel and comment on issues raised in the ad hoc reviews.

The panel members discuss each proposal and then write a panel summary, which is a synopsis of the positive and negative aspects of the project. They also comment on the qualifications and productivity of the investigators. Proposals are then ranked (e.g., excellent, good, fair) or placed in categories (e.g., must fund, possibly fund, don't fund). Based on the summaries, comments, and rankings, the program director makes decisions on which proposals to recommend for funding and starts the process within the agency to notify investigators about the outcomes of the decision process. Most agencies say when decisions will be made; it is rarely a good idea to call or email the agency before this date. Many agencies do not make final decisions until four, five, or even six months or more after the

deadline for submission. If the agency doesn't publicize decision dates, it is acceptable to send a polite email inquiry to your program officer after a few months.

People receiving good news usually receive it first, perhaps within a week or two of the decision. Bad news comes more slowly. Good news or bad, eventually you should receive a set of reviews of your proposal and a written panel summary. We urge you to call your program officer for feedback on failed proposals. We suggest calling any time after you've received the decision, digested the fact that your proposal won't be funded, and are able to talk about it in a receptive manner.

If your proposal was funded, congratulations! If not, don't despair. In this era of limited funding and highly competitive programs, many proposals are not funded on

"CAN YOU BELIEVE MY PROGRAM OFFICER ASKED ME TO STOP CALLING HER EVERY WEEK?"

their first submission. You will probably wish to revise and resubmit your proposal to the same agency. (For more on resubmission, see Chapter 15.) Careful consideration of the panel summary and reviewer comments is an important part of the resubmission process.

Key Points

1. Become familiar with the relevant online submittal system well in advance of the submission deadline so that you don't run into any unexpected surprises.
2. Be prepared to provide a list of potential reviewers with your submission; these should not be collaborators, advisors, or others who pose a conflict of interest. You might consider submitting this list in a cover letter if the online submittal system doesn't have a designated section for it.
3. Become familiar with the review process and expected dates for final decisions. Don't contact your program officer before these dates.

Homework

1. Work with your sponsored programs office representative to obtain the necessary account and login credentials for the online system you'll be using. Spend

some time in the system so that you'll be familiar with it when working up against the final deadline.

2. Prior to starting your submission, develop a list of potential reviewers whose names you can submit with your proposal.
3. Submit your proposal and ensure that you have completed all steps and included all required documentation.
4. Take a huge breath, relax, and reward yourself! Finalizing the submission of your proposal is an accomplishment to be celebrated. Congratulations!

CHAPTER 15

The Three R's: Rethink, Revise, and Resubmit

A rejection offers a learning opportunity. Developing your skills for interpreting reviewer comments and a strategy for revising your proposal will increase your chances of success with a resubmission.

—Marjorie Piechowski, College of Engineering and Applied Science, University of Wisconsin–Milwaukee

It is not uncommon for a proposal to be rejected the first time it is submitted. Funders reject research proposals for many reasons, and even some very good proposals go unfunded. If your proposal is rejected, you will probably feel disappointed, angry, and frustrated. Many of us spend hundreds of hours on our proposals, so it is difficult to receive a rejection, particularly when the proposal you have labored long to produce is returned with only a few paragraphs explaining why it was rejected.

After your initial disappointment, your thoughts will likely turn toward revising and resubmitting your proposal.

A revised proposal usually ends up being much stronger than the first submission. Some granting agencies provide several ad hoc reviews and a written summary of the panel deliberations. If you are lucky enough to receive a large number of reviews, the plentiful feedback will be to your advantage. All scientists benefit from reviewer comments; successful proposal writers use these comments to revise and improve their plans.

In this chapter, we review best practices and general strategies to handle a rejection and to rethink and revise your proposal so you can resubmit it with a better chance of acceptance.

Significantly Improving the Resubmission

Let your disappointment, anger, and frustration subside before you rethink and revise your proposal. Being as objective as you can about the reviewers' comments and about your rejected proposal will help you spot and focus on areas for improvement.

As you begin the revision process, consider seriously each suggestion from all the reviewers—including the ad hoc reviewers, the review panel, the program officer, and any others who provided constructive criticism. Remain open-minded; you do not need to agree with or adopt all their suggestions, but be prepared to support your viewpoint in the

next version of your proposal. Also, your close colleagues or advisors may be able to provide suggestions or help with developing responses to specific comments. It is not unusual to feel that a reviewer or even the entire panel misunderstood something you wrote. Instead, consider the possibility that they did not understand because you did not make your point clearly. Make clarity your goal for revision.

We suggest a two-step approach for rethinking and revising your proposal: first, evaluate the reviewer comments, and second, edit your proposal.

Evaluate Reviewer Comments

Begin by reading your proposal from start to finish. It has probably been a few months since you last read it, so you will see it with fresh eyes. Look again at the reviewer comments. As you examine each remark, try putting it into one of these categories: "must consider," "may consider," and "ignore." If you feel that all of the comments belong in the third category, you are probably not accepting criticism very well. But if the comments are distributed among all three categories, or are primarily in the first two, you are off to a good start.

Review the comments from the first two categories and identify the sections of the proposal to which they are most pertinent. Observe the patterns that arise. For example, you may notice that a large number of issues have to do with

your methods or hypotheses. Or you may find that most concern the scope of your project. This exercise will help you see which sections of your proposal need the most serious revision or were least clearly expressed.

Once you've evaluated the comments, you might consider calling your program officer to ask for any additional feedback on your proposal.

Edit Your Proposal

The extent to which you need to rethink, revise, and rewrite differs for every proposal. Our rule of thumb is to adopt a strategy similar to the one used to conceive and draft the original proposal:

- *Start with the big questions.* Were they clear? Did the reviewers accept their significance? Were the links between your broadest goals and your proposed research plan convincing? If these areas received the greatest criticism, you'll need to rethink your proposal beginning with the fundamental tenets.
- *Funnel down to the specifics of your research plan.* Determine whether your discussion led to misunderstandings in the methods. Did you overlook important papers that could alter your research design? Did you make any mistakes in analysis or interpretation? Did you omit a key set of experiments that could change your final product?

- *Look for strategic errors that could have affected the reviews.* Were you unrealistic in your timeline? Did you fail to highlight key points, or did you overwhelm the key points so that they were lost among details? Was your budget out of line?
- *Discuss the criticisms and your responses with colleagues.* Others may be able to help you understand comments that seem overly critical or that aren't completely clear to you. You can also ask for advice on developing appropriate revisions or responses to particularly harsh comments. Also ask for feedback on the tone and clarity of your responses.

Although reviewers sometimes make suggestions that are not tenable or are off the mark, if you follow this process you should be able to substantially improve your proposal. You have an important added advantage as you resubmit: you now have reviewer feedback and know what areas reviewers found weakest in your first proposal. Make use of this information in your revision. It can only help.

Writing a Resubmission Response

Many agencies require a resubmission response as part of a proposal that has been rejected previously. Some agencies even require an item-by-item response to prior reviews. A resubmission response should be no more than a few

paragraphs long, since it is usually counted as part of the main body of the proposal and falls within page restrictions. As with responses to peer-reviewed publication submissions, it is advisable to summarize the major comments made by the reviewers (positive as well as negative) and describe how these comments were incorporated into the revision or why you chose not to assimilate them. It is important to maintain an objective tone and not sound defensive in your resubmission response, even if you don't agree with the reviewer comments or thought they were unfair.

A resubmission response is valuable for a number of reasons. First, it allows you to carefully consider each reviewer comment and to check your response to it. Second, it guarantees some institutional memory for your proposal. If the initial reviewers agreed that you wrote an excellent proposal and that the only major weaknesses were in the methods, you should remind the panel of this in your revised submission. This response puts some pressure on the agency to acknowledge the previous review, even if the revised proposal is read by new program officials and reviewers. Finally, it draws attention to the improvements you have made.

Some agencies require the resubmission response to be placed at the beginning of the project description, and others want it placed just before the references. Depending on the agency, you may also place it in your cover letter. A

well-written response can be used to highlight key points or deflect key sources of potential concern, so placing it early could be advantageous.

Key Points

1. It is not uncommon for a proposal to be rejected the first time it is submitted. If this happens to you, it is natural to feel disappointed, angry, and frustrated. Recognize these feelings and let them subside before you begin your revisions in earnest.
2. Use a two-step approach to rethink and revise your proposal: evaluate the reviewer comments and then edit your proposal.
3. In your resubmission response, summarize the major reviewer comments and describe how you have responded to them and incorporated them into the revision.

Homework

1. If you have received a rejection that includes reviewer comments, take some time to process your feelings and to absorb the feedback before you begin the revision process in earnest.

2. Once you're ready to begin, start the process of evaluating and categorizing the reviewer comments.
3. Assess reviewer comments for any patterns that arise.
4. Begin editing your proposal by using an approach similar to the one you used for the first draft. Start with the big picture and funnel down to the specifics. Be sure to address any strategic errors you may have made.
5. Draft your resubmission response.

CHAPTER 16

Funding Innovative Research through Private Foundations

> The grant development process with a private foundation is iterative, and active engagement with the program officer is key. Furthermore, building an honest and transparent relationship is important because your program officer will serve as your internal advocate through the approval process.
>
> —Camellia Pham, Science Program, Heising-Simons Foundation

Colleagues often ask us where they can find support for innovative work that falls outside the purview of traditional federal research agencies. Increasingly, the answer can be found by turning to private foundations. Foundations in the United States are funding a significant amount of research. In 2012, private foundations awarded approximately $1.5 billion to investigators for medical research and $600 million for science and technology areas (Foundation Center 2014). Each year, individuals and families pass an increasing amount of personal wealth to private foundations for philanthropic purposes. Most academic researchers are not

familiar with the aims or scopes of private foundations, but developing this understanding is worth the effort. Support from foundations for exciting, creative ideas, particularly those developed "outside the box," is growing increasingly important not just to researchers seeking funding but to the advancement of science and technology.

In this chapter, we discuss the basics of private foundation funding and explore the differences between applying for funding from private foundations and applying for funding from government agencies.

Getting Started with Private Foundations

The basic precepts for effective communication discussed in Chapter 3—*organize, highlight, funnel, focus,* and *unify*—hold true for all proposals, including those to private foundations. Your application will be strong if you adhere to the basic guidelines of knowing your audience, expressing a compelling vision, and demonstrating competence and ability to conduct the study. Avoid such common pitfalls as failing to establish its general significance, failing to link your ideas to the specific work plan, overlooking critical information, and making a sloppy presentation. In fact, because foundation proposals are often much shorter than federal proposals, avoiding these pitfalls is even more crucial. We keep in mind the (paraphrased) Mark Twain saying, "I didn't

have time to write an article, so I wrote a book." You're writing an "article"; your goal is brevity and succinctness. Allow plenty of time to write an application for private foundation funding, and make sure every detail is honed.

Although crafting a proposal for a foundation is similar to crafting one for a federal agency, there are noteworthy differences, and there is no template for designing effective foundation proposals. We presented a general model for federal agencies, but the mission of every foundation is unique, and criteria for funding are extremely diverse. We urge you to contact the office at your institution that handles foundation relations, because this landscape is volatile and serves those who are opportunistic. Success with foundations typically relies on personal relationships, which take time and foresight to develop. It is important to develop these relationships before you submit your first foundation proposal.

Foundation Basics

Private foundations are generally charitable entities established by individuals, families, or organizations, such as corporations, with specific goals and missions. Foundations control a pool of money, known as an endowment, that generates income used to support the goals of the foundation. In the United States, foundations are defined by the Internal Revenue Service tax code and are required by law to give

Selected Foundations with Total Dollar Amounts Awarded to Science and Technology in 2012

Foundation Name	State	Dollar Amount (millions)	Number of Awards
Gordon and Betty Moore Foundation	CA	$96	75
The Simons Foundation	NY	$53	119
David and Lucile Packard Foundation	CA	$52	29
Alfred P. Sloan Foundation	TX	$50	189
The Lemelson Foundation	OR	$26	6
Robert A. Welch Foundation	TX	$21	353
Intel Foundation	OR	$19	97
W. M. Keck Foundation	CA	$15	25
Bill and Melinda Gates Foundation	WA	$9	42
M. J. Murdock Charitable Trust	WA	$3	27

Source: Foundation Center 2014.

away a certain portion of their funds each year. They usually have very specific guidelines about the topics, organizations, and individuals they fund. The top foundation funding sources specifically targeted for scientific, health, technology, and environmental research are listed in the accompanying table.

Most foundations that fund scientific studies stick to several general categories. Be aware that even these broad themes can change over time, so be sure to gather up-to-date information about each foundation to gauge its current areas of focus. There are four general research themes.

Region. Many foundations support economic or social growth in a specific region, either American—such as the northeastern states, the Colorado River watershed, western Pennsylvania, the Sierra Nevada, the Sonoran Desert—or in a specific international area, such as the Arctic or the Amazon River Basin.

Target group. This is a much broader category than "region," and new additions arise according to societal priorities. For example, in some years funding may be very high for supporting K–12 educational outreach programs, advancement of underrepresented minorities in science, junior faculty, or mid-career advancement of women.

Topic. Some foundations have a general set of guidelines and focuses, like cancer, diabetes, sustainability, climate change, poverty, or disease.

Investigator level or prestige. Many foundation programs are designed to support junior investigators who show outstanding potential and are selected in large competitions. In these cases, an institutional representative usually nominates the investigator, and quite often institutions can nominate candidates only by invitation, and the number of nominees is often limited to one or two per institution. Such awards are usually announced by the administration of your institution and may be listed on the web page of your sponsored programs office.

Other awards are intended for national and international leaders in their disciplines. The merit criteria are usually rigorous for these types of programs, so awards are often considered prestigious.

Every foundation is different, however. Here are some general guidelines to think about as you begin to explore these sources of funding.

- Foundations like to fund innovation and can support high-risk projects or provide early seed funding to get a project started.
- Foundations want to make a difference and will make quick decisions to address emerging problems.
- Foundations often award money to projects that are not fundable by federal or state agencies because they do not fit precisely within the agency mission or existing solicitation criteria.
- Foundations are not required to offer detailed descriptions of their review process or follow the same procedures every year for awarding money—they have more latitude for rapid change than do federal agencies.
- Foundations often have specific objectives for the projects they will support, yet these may not be stated fully in any publicly available documents.

- Some foundations have programs with fixed due dates, but others accept unsolicited letters of inquiry or applications at any time. Some will not accept unsolicited queries.
- Some foundations will not work directly with individuals or sole-investigator projects, whereas others prefer to do so.
- Proposals for foundations are often short, sometimes in the form of a letter, so persuasive writing is crucial to your success.
- Foundations often fund a person rather than a specific project, so your reputation can play a decisive role in the success of your application. Some foundations have long memories. A poorly written proposal could result not only in the denial of a specific request but of all submissions from you (or your institution) in the future.
- Personal meetings with foundation personnel may be needed before a solicitation will be accepted, so prepare to spend time laying the groundwork for your application.
- Many academic institutions coordinate all requests to foundations. Discuss your ideas and targeted foundations with people in your institution's sponsored programs office before you make contact.

You can find out about specific foundations in many ways, such as conducting a web search, visiting the website run by the Foundation Center (foundationcenter .org), or keeping track of foundations mentioned in the acknowledgments of publications in your field. However, such material may not be detailed or current. The best way to get started with foundations is to talk with colleagues who have received foundation support and to talk with staff in your sponsored programs or foundations office. They can help you learn how to identify foundations that might welcome an inquiry from you or from others asking on your behalf.

"DEAR PRIVATE FOUNDATION,

CAN WE MEET FOR COFFEE?

YOURS TRULY,
RESEARCHER WITH INNOVATIVE IDEA"

How Do Foundations and Federal Funding Agencies Differ?

Like federal agencies, foundations usually fund nonprofit organizations (including colleges and universities) but also, less commonly, individuals or corporations. However, unlike federal agencies, foundations are more eclectic in their funding priorities. These priorities may change rapidly—for example, when a new foundation president or program staff member comes onboard and contributes new goals and objectives. Foundations also like to be flexible in order to meet what they perceive to be rising community, national, and international priorities that are not funded by other sources. The selection criteria and decision-making processes vary widely among foundations.

Review process. Private foundations are less likely to provide detailed descriptions of their proposal review procedures. Foundation proposals always undergo some form of review—often peer review—but the nature of that review is much less well defined or transparent than for the reviews of federal agencies. Nevertheless, it is helpful to try to learn who the audience will be for your foundation proposal. In the case of a foundation proposal, it is unlikely that your audience will be entirely nonscientific staff. However, because it is possible that your audience will not include scientists, you should determine the nature of your reviewers before you start writing.

Coverage of costs. The types of initiatives or costs that will be covered by foundation awards vary widely. As a rule, you will need to clarify the acceptability of each type of cost you propose to a foundation. For example, some do not allow payment of investigator salaries. Some allow support for travel costs, entertainment, living expenses, and per diem expenditures. Purchase of equipment, advertising for positions, consulting, and computational costs may or may not be allowed. Additionally, some foundations do not allow the inclusion of indirect costs in their awards, while others allow a small percentage of the total cost to be charged as "administrative costs." In these cases, you will need to discuss with your home institution its flexibility in policies regarding grants and adjustment of indirect costs. A few institutions discourage applications to foundations because of the possibility of lower indirect costs, but most welcome foundation awards, despite lower or no indirect cost recovery.

Cost sharing. It is quite common for private foundations to require that their money be used to "leverage" other projects or costs. In fact, as a program officer at one foundation told us, program officers at private foundations often communicate with program officers at federal agencies to identify initiatives that are complementary to the agency's funding priorities. Leveraging is accomplished by enhancing or building off another project. There are many ways to achieve this goal. You could show how foundation support will extend an ongoing project into a new area with a dis-

tinctly different and large payoff. You could also outline additional projects that you or your institution would develop as part of the proposed research, to be funded by another agency. Leveraging an investigator's salary is also very common; in this case, your institution would cover the salary of the principal investigator as its contribution, and the foundation would pay for other initiatives.

Project initiation. Foundations often allocate funds to institutions initiating new programs with the expectation that the institutions will eventually support the programs on their own. Such conditions must be carefully considered; foundations increasingly require evidence of institutional commitment to projects before making an award. Again, we emphasize the value of talking with administrators at your home institution before submitting your proposal. Commitments can include matching funds, written assurances of plans to continue a program, and in-kind service. The foundations administrator at your home institution should be able to assist you in determining the best way to meet these expectations.

Considerations as You Begin with Foundations

Spend some time with a senior colleague or a person in your administration before fully engaging in the process of pursuing private foundation support. Gather as much

information as you can on your institution and its relationships with particular foundations. Often people do not approach foundations until they have been funded by more traditional funding agencies, so it is often the more established researchers who receive foundation support—but not always. Because of the differences between private foundations and federal agencies, particularly where transparency and peer review are lacking, some private foundation funding may not be considered as prestigious as federal agency funding when tenure and promotion are in question. Before spending too much time preparing a proposal, we suggest that junior faculty talk to senior colleagues or academic deans about the implications of receiving foundation funding. Also bear in mind that foundations with a known political agenda or particular desired outcome may carry less credibility among academics. Again, be sure to talk with colleagues to determine the reputation of a foundation and its suitability as a funding source and how these might affect your professional position.

Since the foundation landscape is constantly changing, your options and chances could improve considerably from one year to the next, and we encourage you to reexamine foundation websites periodically. We also emphasize the need to treat foundations and foundation officers with respect. Long-term personal relationships can be extremely important and are quite different from those you develop

with program officers at federal agencies. Being careless or sloppy can have implications for your chances with private foundations long into the future.

Crowdfunding

When we wrote the first edition of this book, it was inconceivable to think that researchers would one day be soliciting funding from the general public through the web—but times have changed! There are now examples of both PI's and students who have successfully raised funds through crowdfunding via the web (for example, through Experiment.com). If this interests you, we suggest using some of the same principles suggested for pursuing private foundation funding. The major difference is that you won't necessarily ever know, or directly interact with, your funders.

As with the proposals submitted to private foundations, you should keep your message short, clear, and focused. Hone your marketing skills to make your project stand out online. You might have only enough space for a paragraph or two to pique the interest of potential donors. This approach has proven successful for smaller dollar amounts, such as the amount needed for a graduate student to conduct summer fieldwork or for a researcher to purchase a specialized instrument to analyze data and produce results that are of interest to the general public (e.g., DNA research,

localized environmental analysis, health information to increase the survival of endangered species).

Since crowdsourcing is a relatively new method for receiving funding, be aware that there may be pitfalls—for example, if a crowdfunded research project does not undergo any peer review, reviewers or tenure committees may not consider it high quality when it comes time to publish the results. Be sure to check with your department chair or dean to determine if there are any restrictions on pursuing crowdfunding.

Exercises for Writing Proposals to Private Foundations

EXERCISE 16.1. (This follows from the exercises given in Chapters 4, 7, and 9.) Start by doing some exploratory work. The best way to begin is to consult with colleagues and administrators to identify foundations with interests that align with yours. In addition, read foundation websites carefully, noting the topics and projects being funded, the size of awards, and the geographic locations of funded activities. Read published outputs and annual reports from foundations where available. You will want to contact a foundation officer before submitting a proposal, but as we emphasized earlier, check with the foundations administrator or sponsored programs office at your institution before doing so.

EXERCISE 16.2. Spend some time thinking about how to diversify your work by developing a number of ideas or perspectives. The match between you as the investigator and a particular foundation as potential funder may be highly dependent on the context you use to present the study. Staff at your institution may be able to help you decide which parts of your proposal to emphasize or highlight when approaching different foundations. Sometimes this means looking at your project in a completely new way. For example, we have colleagues who can take aspects of the same work and highlight different parts in order to appeal to the NSF, NASA, NIH, and American Heart Association. Use this same type of thought process when developing highlights to emphasize for private foundations. Bear in mind the four general research categories funded by most foundations—region, target group, topic, and investigator level or prestige—and consider how your work would fit within each category.

Key Points

1. Developing proposals for private foundations is similar to developing them for federal agencies, including use of the basic precepts for effective communication discussed in Chapter 3—*organize, highlight, funnel, focus,* and *unify.* However, proposals for private funding are usually much shorter than those for federal

funding, so it is important to be clear and concise to establish the significance of the project and catch the attention of funders.

2. Having a proposal accepted by a private foundation usually depends on having developed a personal relationship with the program representative at the foundation prior to submission.

3. With private foundations, there are many variables when it comes to what types of projects a foundation will fund, how proposals are reviewed, and even what costs can be included for funding (such as PI salary or indirect costs). Work with your sponsored programs office and the person who handles private foundations to learn the details.

Homework

1. If you've completed the exercises in this chapter and are ready to pursue private foundation funding, meet with your sponsored programs administrator to learn how the process works at your institution. This is also a good time to reach out to the program officer at the foundation if you haven't already done so.

2. Once you're ready to develop and submit your proposal, use the five precepts for effective communica-

tion as you write—*organize, highlight, funnel, focus,* and *unify*.

3. Once you have a draft proposal, reread and rewrite, and have colleagues review it for you until it really shines. Ask your colleagues if the significance is well established and clearly linked to the work plan.

CHAPTER 17

Team Science for Tackling Complex Problems

> A critical, and often overlooked, ingredient in making scientific breakthroughs is the ability to truly integrate specialized skills and processes from a variety of fields, such as engineering, physics, and computation, with the life sciences.
>
> —Justin Chen, Biology Department, Massachusetts Institute of Technology

As knowledge and access to information continue to expand at an explosive rate, the need for multidisciplinary teams of scientists to work on complex scientific problems is greater than ever. Not long ago, a biologist working with a chemist was considered interdisciplinary. Today, scientists collaborate with experts in fields spanning the natural sciences, engineering, the social sciences, and the humanities.

Federal agencies and private foundations have programs to bring together multidisciplinary teams to address problems that affect public health and well-being, such as climate change, cancer, and infectious diseases. Even more

traditional proposal review panels sometimes contain one or two panelists from outside the primary discipline because investigators are frequently co-authoring proposals with colleagues outside their disciplines. For many scientists, multidisciplinary research—so-called "team science"—is invigorating. Working with scholars who use different vocabularies and methodologies will drive you to challenge your own assumptions. Multidisciplinary collaboration is regularly taught and reinforced throughout undergraduate and graduate careers. We find tackling problems in this way highly rewarding and encourage our students and colleagues to do so when appropriate.

In this chapter, we describe the different types of multidisciplinary research and the typical requirements for multidisciplinary proposals, including the issues posed by their expanding breadth and administrative complexity.

What Is Multidisciplinary Research?

There are many types of multidisciplinary proposals; even a single-author proposal can be, in some sense, multidisciplinary. In this chapter, however, we are referring primarily to "team science," where the proposal involves collaborations with investigators from different disciplines, often from different institutions or from different schools within the same institution. Such proposals differ from

more traditional proposals primarily in complexity and breadth, and they generally have larger budgets and may be funded for more years.

Several terms are commonly used to describe various types of multidisciplinary research:

- *Convergence science* is the integration of knowledge, specialized skills, and processes across a variety of fields. It merges engineering, physical sciences, health and life sciences, computing, and other fields to build on fundamental progress made within individual disciplines by creating comprehensive frameworks to tackle scientific and societal challenges at the interfaces of multiple fields (Sharp et al. 2016; National Research Council 2014).

- *Systems science* is the study of systems and their subsystems as systems (e.g., global systems, biological or ecological systems, social systems, economic systems) by investigating their general and useful attributes, dynamics, characteristics, and behaviors (Mobus and Kalton 2015).

- *Integrative science* is a cumulative approach to a question or problem. The perspectives of individual disciplines are synthesized and integrated during all phases of the research (T. K. Gallagher et al., "Making the Case for Integrated Science" [2008], as cited in Weber 2012).

Why Multidisciplinary Research May Be Right for You

Working with a diverse team of collaborators enables a researcher to ask complex and globally significant questions, include new techniques via collaborations, and synthesize across disciplines. The rewards are great, but the demand on time and resources will be considerable. There will be more people to manage and more complex finances, more institutional rules, and additional research details to consider and track.

Over a decade ago, the National Academy of Sciences concluded that multidisciplinary thinking was "rapidly becoming an integral feature of research" (NAS 2005). It identified four elements pushing this forward:

- The inherent complexity of nature and society
- The desire to explore problems and questions that are not confined to a single discipline
- The need to solve societal problems
- The power of new technologies

These elements are important ingredients of scientific proposals accepted for funding. Multidisciplinary proposals share the elements that we have presented throughout this book, so most of the chapters also pertain to collaborative proposals. Some agencies specifically ask for collaborations

across divisions and disciplines, and sometimes investigators are asked to search for individuals to add a "human" dimension or a "science" aspect to a project. If you are already collaborating with diverse groups, you are an ideal candidate for a multidisciplinary proposal.

Typical Multidisciplinary Proposal Requirements

Writing multi-investigator and multidisciplinary research proposals is more challenging than writing traditional single-investigator, single-discipline proposals. Because of their breadth, successful proposals for team science depend heavily on effective language and tight organization. The more complicated the problems, the more links among aspects of the research, and the more people and institutions involved, the less space there is to elaborate on any individual idea. Every word becomes critical. Every aspect of the project needs justification. And the gap between reviewer expertise and specifics of the work can be large.

Writing a persuasive multidisciplinary proposal requires special attention to the five precepts of proposal writing—*organize, highlight, funnel, focus,* and *unify*—especially to *unify.* A multidisciplinary proposal must have a cohesive, compelling framework that unites the various pieces and underscores its greatest value. Your reviewers will be asking

themselves whether the sum of the work is greater than its parts. You will need to convince them that your questions warrant a team, that the study holds together, and that your team will be more successful and effective than individuals or smaller groups evaluated separately.

A number of key areas deserve particular attention when writing a multidisciplinary, multi-investigator team science proposal.

- *Length and language.* Multidisciplinary proposals often have the same length constraints as other proposals, yet typically they need to cover more topics. Success is achieved only if the writing is succinct and the words well chosen. Carefully consider the need for each reference and the amount of detail necessary for each method and analysis. Schematics and well-developed timelines help demonstrate how parts of the project are coordinated. A concise title that somehow conveys the breadth of the work without making it sound complicated will set the right tone.
- *Unifying the voices.* In spite of the teamwork involved in multidisciplinary proposals, the best proposals read as if they were written by one person. Parallel organization and consistent terminology help unify the voices, underscore the value of the collaborative approach, and help the reviewer keep it all straight.

Whatever you can do to make the proposal simple, elegant, focused, and easy to follow takes extra work but is worthwhile.

- *Institutional and program rules.* Multidisciplinary proposals often have specific rules regarding the preparation of budgets, investigator credentials, and links between institutions. Coordinating rules across institutions often takes time and cooperation. There can be challenges even when collaborators come from the same institution if internal schools or programs have different administrative rules or rates—e.g., indirect-cost rates. Collaboration among large numbers of investigators often requires certain costs for grant management, project management, data management, building renovation, community outreach, and so on. Obviously, planning is essential. Understand as many of the rules as possible early in the process to avoid delays when finalizing or submitting the proposal. All large and most smaller institutions have staff in the grants and contracts offices who can assist with these aspects of the proposal. The institution of the lead PI usually undertakes the final coordination of the submission.
- *Managing people.* As the number of people involved increases, the necessity for effective and transparent

management becomes even greater. Funding agencies often require that project management plans (described in Chapter 11) demonstrate how a multidisciplinary proposal will be managed. In many cases, investigators come from different institutions, so the need to define roles and lines of communication is particularly strong. As we discussed in Chapter 2, establishing clear expectations for authorship, duties of the various investigators, and access to and use of the data will increase the success of the project. It will also reduce the chance for misunderstandings.

- *Ethical considerations.* Ensuring that everyone follows all rules (see Chapter 18) becomes more complicated as the program grows in personnel. The PI is ultimately responsible for ensuring the integrity of the project and its management, but all project members should fully engage in discussions about topics such as spending funds appropriately and following regulations. Transparent decision-making with group input always increases the likelihood that the program will be run efficiently and ethically.
- *Significance to merit the project's size and complexity.* Previous discussions of significance, objectives, and overarching goals have underscored the importance of these elements to the success of all research proposals.

(See Chapter 4 for more on significance and Chapter 7 for more on objectives and goals.) As the complexity of the research question grows and the size of the investigative team expands, so too must the significance. Connecting the actual work to the overarching goal is crucial. As reviewers, we have found this to be a common pitfall of team science. The question may be compelling and the team impressive, but links between the pieces are often underdeveloped. As a result, the vital element that makes the sum greater than its parts is missing, and the proposal may not be successful.

- *Unifying the research.* Each part of a multidisciplinary project must be seen as essential to accomplishing the overall objective. The most effective proposals include a section that points out the links between sections and reinforces the overall research themes. These proposals frequently include explicit plans for synthesizing the work and data in the project management plan.
- *Data management.* Some funding agencies require a specific plan for coordinating, managing, and synthesizing the data. With investigators across several disciplines, it is important to develop a data management plan in the beginning to determine how the data will be collected, processed, and analyzed. Researchers

from different disciplines often use different software, statistical methods, and even units of measurement. Synthesizing the final results will be easier if differences are resolved at the proposal stage. It is helpful to develop a single database or repository of project data online so that all team members will have access to the data.

- *Cost-sharing requirements*. Not just the funding agency but the institutions of investigators are routinely expected to make contributions for large multidisciplinary proposals. Determine at the start if the funding agency has requirements for matching funds, cost sharing, graduate stipends, and other types of in-kind assistance, and explore this with your home institution as well.
- *Understanding the reviewer process*. The National Academy of Sciences once recognized that certain funding organizations were reluctant to fund multidisciplinary research because "it requires risk taking and administrative complexities" that typical research does not require (NAS 2005). For example, a traditional panel of reviewers is probably not sufficient for reviewing multidisciplinary proposals, so even the task of assembling a panel becomes more complex. The panels reviewing multidisciplinary proposals must be diverse because

they have to cover broad areas of research. It follows that many or even most reviewers will not be familiar with every field of expertise in the proposal. As we noted for foundation proposals, some of the reviewers also may be nonexperts. The hesitancy to fund multidisciplinary research has decreased in recent years, and some agencies actively encourage it, but the challenges associated with managing it remains. For these reasons, we urge you to fully understand the reviewing community before writing your proposal and to craft different sections of the proposal to be accessible to the different types of reviewers. For example, methods should be described in sufficient detail for experts to evaluate them, but significance should be accessible to all reviewers. A strategic discussion with the program director can be very helpful in learning how the review process will be handled.

Exercises for Getting Started

The exercises presented in other chapters are all appropriate for multidisciplinary proposals. The drills here are meant to assist you with getting collaborations under way and unifying research for the project.

EXERCISE 17.1. (This follows from the exercises given in Chapters 4, 7, 9, and 16.) Multidisciplinary research teams

often consist of both experienced and new researchers at all career levels. Their presence offers great opportunities for mentoring while the research is being conducted. If you are a newer investigator, we encourage you to approach senior colleagues to ask whether they know of any mentoring opportunities. It is much easier to start out as a co-PI or collaborator on a large project led by an experienced investigator than it is to organize a project yourself. You can also talk to your academic administrators to identify internal programs that can support the development of larger projects and collaborations. It is not uncommon to apply for internal funds for pilot research before bringing together a coalition of scientists to write a multidisciplinary proposal. Similarly, you might consider developing a symposium at a conference or at your institution to bring together potential colleagues to think broadly about a research topic. These activities often lead to collaborations, and they have merit on their own for establishing exciting scientific connections.

EXERCISE 17.2. In the development stage, take time to outline how the disparate aspects of the work are unified. The unifying themes will need to be reinforced in all sections of the proposal. You can also construct a diagram to make the links very clear. Consider sharing the overarching significance with colleagues in a variety of fields to determine whether the content is compelling even to nonexperts and ask colleagues whether the title provides insight into

the larger goals. During the writing process, make sure that every section is explicitly tied to the unifying themes in some fashion; use headers to unify sections; and include a precise plan to synthesize results throughout the project rather than waiting until the research has been completed.

Key Points

1. Tackling complex scientific problems with multidisciplinary teams of scientists is more important than ever as we seek to understand and solve problems that affect public health and well-being. Moreover, working with scholars from disparate fields who use different vocabularies and methodologies is invigorating and will drive participants, including you, to challenge their own assumptions.
2. Writing multidisciplinary proposals requires extra attention to the fifth precept: *unify*. You will need to convince reviewers that the sum of the work is greater than its parts and that your questions warrant a team to answer them.
3. Crafting multidisciplinary proposals poses challenges in several key areas, making it important to develop comprehensive project management plans that address personnel, data, and cost management.

Homework

1. If you have completed the exercises in this chapter and are ready to assemble your team and write a multidisciplinary proposal, begin by revisiting the homework assignments in Chapter 2.
2. Next, organize the tasks among your team members for writing the sections of the main proposal as well as additional components such as the project and data management plans.
3. Once your team members have completed a first draft, review and revise to unify it into one voice.

CHAPTER 18

Ethics and Research

> Even if misconduct is rare, it can have a tremendous impact on research. Consider an analogy with crime: it does not take much to erode a community's sense of trust and increase fear and paranoia. The same thing is true with the most serious crimes in science, i.e. fabrication, falsification, and plagiarism.
>
> —David B. Resnik, National Institute for Environmental Health Sciences, NIH

The conduct of science assumes that the people involved are going to be honest and trustworthy (Macrina 2005). When you conduct scientific research, you accept full responsibility for ensuring the integrity of your work and compliance with special regulations. If you accept financial resources to conduct your research, you are also fully accountable to your institution, the scientific community, and the funding agency. Anyone who enjoys the privilege of leading a laboratory has a further responsibility to make certain that their students and colleagues also understand the expectations and standards required (Schrader-Frechette 1994).

In this chapter we point out a few topics related to ethics that should be understood by all graduate students, faculty, and investigators involved in scientific research. We urge you take a class or participate in a seminar or reading group on this subject at some point in your career. Most research institutions offer such courses for graduate students or even require them, and some funding agencies require that their recipients complete one.

Consider Ethical Issues

Many ethical challenges can arise during the course of conducting scientific research. Some challenges, such as using proper citation techniques, sorting out ownership of ideas, and managing budgetary oversight, have been discussed in other chapters. In this chapter, we identify five general areas in which ethical standards must be maintained. Reflecting on these vital aspects of conducting research is a useful exercise to ensure that you maintain the integrity of your work. Our own students and colleagues enjoy talking about these issues, and our programs have benefited from the conversations at all phases of proposal development and implementation.

1. *Give appropriate credit*. As you write your proposal, and as you present your ideas to others informally or in seminars, recognize the contributions of others. It is always appropriate to acknowledge that certain ideas in your proposal

derive from the work of others. As we discussed earlier, giving credit can reduce the chance for more complicated problems, such as authorship disputes and the need for scientific oversight to maintain the integrity of the data. Early, frequent, and open communication significantly reduces the possibility of disputes among investigators.

2. *Respect people, animals, plants, and the environment affected by your research*. Federal, state, and institutional regulations to ensure ethical treatment are common, and you must ensure compliance with these regulations. All academic institutions have committees that routinely review research involving human subjects and vertebrate animals for compliance. Many funding agencies require specific information on plans for compliance to be included in the grant application. However, even if your research does not fall under these regulations, try to minimize unnecessary impacts of your activities. A discussion of this with colleagues could be useful, especially for beginning researchers and graduate students. Other areas that might require special compliance include classified research, access to specialized instruments, and the operation of remote-control submarine or aerial vehicles (such as drones).

3. *Remain objective*. Although no one starts out intending to falsify data, scientific misconduct occurs and is always devastating to the scientific community. The best ways to avoid such problems are remaining objective, avoiding any

guesses about your results, and sharing with others your decisions about data analysis and interpretation. For example, a researcher may become so convinced of the outcome of an experiment that he or she ignores or dismisses contradictory results. Or an investigator may choose to conduct experiments that favor particular outcomes. By discussing your decisions openly, you will reduce the chance of biasing your approach or results. Scientists have many ways to ensure the validity of research (e.g., peer review, publication of results and data), but it is far better to avoid problems than to have them discovered in the review process. Sharing your ideas and research designs, encouraging and soliciting criticism, and being self-critical will ensure that you remain objective throughout your research career.

4. *Spend money appropriately.* Accepting financial support for research constitutes an agreement that you will spend the award money on the approved research and that you will follow all guidelines for reporting your use of funds. Different agencies have specific regulations concerning the shifting of money from one budget category to another. Deviations from the original, approved budget often require explanation, justification, and permission from the agency. Expenditures on non-research items and wasteful spending are never permissible. Financial misconduct is not tolerated, regardless of intent or ignorance. (It is not a defense to say that you did not understand.) To avoid such problems,

"NICE TRY WITH THE ESPRESSO MACHINE AS LAB EQUIPMENT..."

maintain close relationships with your granting officer and ask questions whenever you are unsure of regulations.

5. *Be attentive to possible conflicts of interest (COI).* Identify any COI—or any situation that might even appear to be a conflict of interest—to the appropriate people at your institution before you submit your proposal. A COI typically occurs when a person's private interests interfere or conflict with the obligations or responsibilities that person has in a public capacity, usually a job. If you have personal financial interests (stocks, investments, etc.) that might benefit from the outcome of research you propose to do, you should definitely talk to the appropriate people at your institution about a possible conflict of interest. When you work with a

Integrity in Scientific Research

The individual scientist agrees to the following when he or she undertakes scientific inquiry:

- Intellectual honesty in proposing, performing, and reporting research
- Accuracy in representing the contributions of individuals to developing and writing research proposals and to subsequent reports and publications
- Collegiality in scientific interactions, including oral and written communications and use of resources
- Protection of human subjects, humane care of animals, and responsible treatment of the environment
- Respect for the individual and collective responsibilities of investigators and their research groups

Source: Modified from Institute of Medicine and National Research Council 2002.

close relative, a partner, or someone with whom you have a deep personal or romantic relationship, you should consult with your institution about proper reporting pathways. Most institutions have guidelines that can be very useful and will assist you with avoiding problems associated with COI. See, for example, those of the National Research Council, included in the above table.

Use the Guidance and Advice of Others

Our strongest recommendation is to seek guidance from others. Whenever you have ethical questions—whether you are a first-year graduate student or an experienced researcher—the best approach is to talk to colleagues and

mentors in your field and to officials at your institution who handle these types of issues. Discuss your potential difficulties with those you respect, and you will almost certainly avoid seeing your difficulties become dilemmas.

Key Points

1. Accepting financial resources to conduct your research makes you fully accountable to your institution, the scientific community, and the funding agency. You are also responsible for making certain that your students and colleagues understand the ethical expectations, standards, and compliance required.
2. There are five general areas where ethical standards must be maintained: in giving proper credit; respecting people, animals, plants, and the environment; remaining objective; spending money; and avoiding conflicts of interest.
3. Always seek guidance from colleagues and officials at your institution or funding agency to understand compliance requirements and avoid ethical issues.

Homework

1. First, familiarize yourself with the common ethical issues that arise in scientific research, the types of

research that requires special compliance, and the types of conflicts of interest that can occur. Start by asking colleagues for examples that typically occur in your field.

2. Next, explore whether your institution offers a class or seminar on ethics and whether your funding agency has requirements for specialized training or certification to meet compliance requirements.

3. If you have concerns about your own research, talk to your colleagues and your superiors to learn how best to report these concerns and avoid trouble down the road.

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Useful Links

https://careerdevelopment.aaas.org/course-catalog/avoiding-common-errors-proposal-writing/
Charles Dunlap, "Avoiding Common Errors in Proposal Writing," an AAAS short course. AAAS is the American Association for the Advancement of Science.

http://cris.csrees.usda.gov
: The Current Research Information System (CRIS) of the National Institute of Food and Agriculture, U.S. Department of Agriculture.

https://www.epa.gov/research-grants
: Environmental Protection Agency (EPA) research grants information.

http://foundationcenter.org
: The Foundation Center website for information and data on private foundation funding.

https://www.gsa.gov/portal/content/104877
: General Services Administration (GAA) website for determining the government's per diem rates for food and lodging.

http://www.grants.gov
: Online grants management tool for all federal agencies.

http://www.nasa.gov
: Homepage of the National Aeronautics and Space Administration (NASA).

https://projectreporter.nih.gov/
: Website of the National Institutes of Health (NIH) Research Portfolio Online Reporting Tools (RePORT).

http://www.nsf.gov
: Homepage of the National Science Foundation (NSF).

https://www.fastlane.nsf.gov
: National Science Foundation (NSF) web portal for proposal submission and management.

https://service.govdelivery.com/accounts/USNSF/subscriber/new
: Webpage to sign up for emails on funding opportunities offered by the National Science Foundation.

http://www.research.gov
: Online grants management tool for the National Science Foundation (NSF) community.

http://www.nordp.org
The National Organization of Research Development Professionals homepage.

http://physics.illinois.edu/people/directory/profile/cmelliot
Website of Celia M. Elliott, who is in the Department of Physics at University of Illinois Urbana-Champaign, with links to her many online articles and tutorials on writing, both in general and for science proposals.

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* The views expressed in this book do not necessarily represent the views of the National Science Foundation or the U.S. government. These materials were prepared before the author joined NSF.