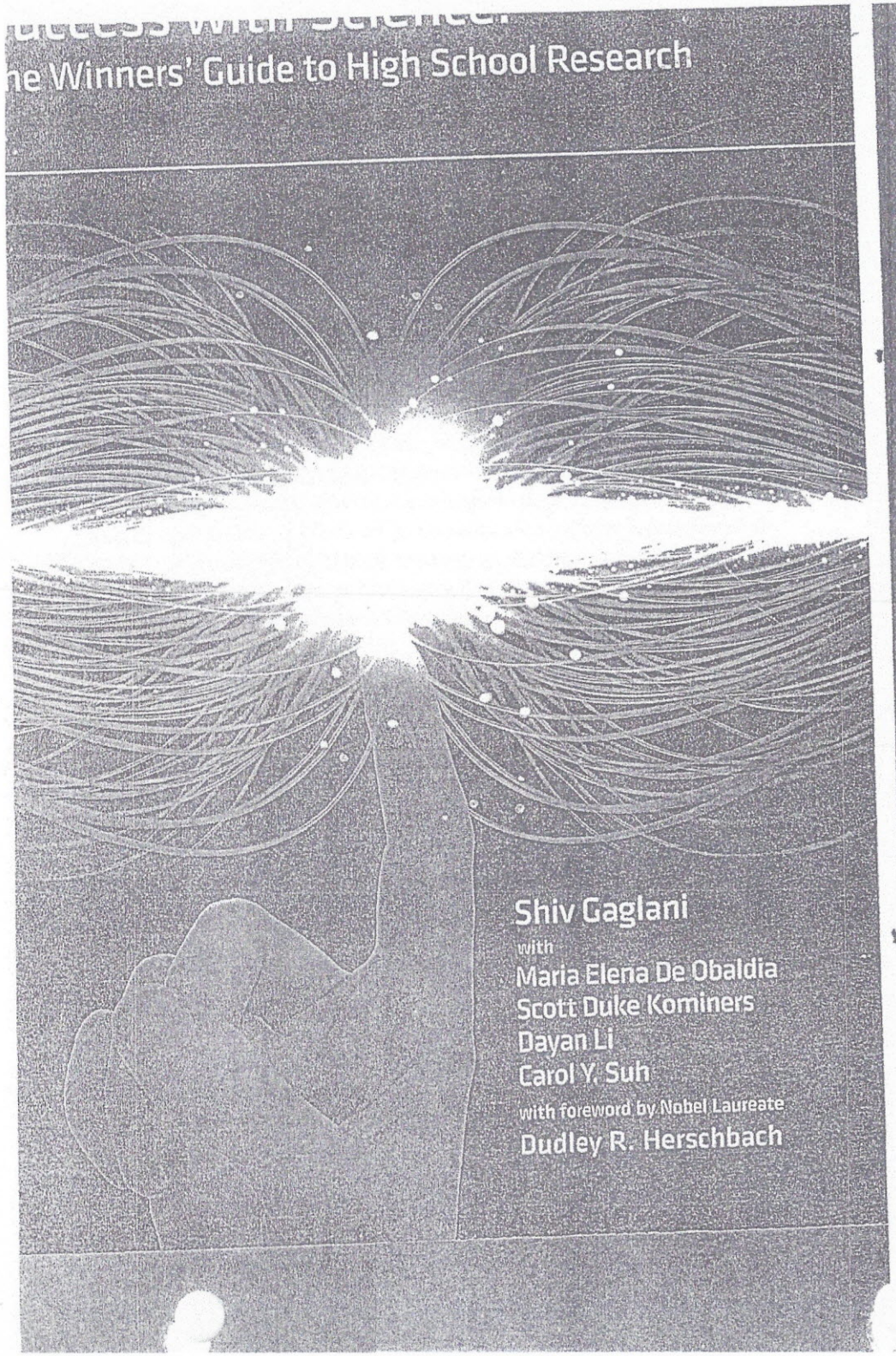

Formulating an Idea

The best way to have a good idea is to have a lot of ideas.
Linus Pauling

Introduction

Formulating a research idea is not a one-time effort, but rather a continuous process. Inevitably, an initial idea develops over time as research takes unexpected turns, gains complexity and becomes more specific. Sometimes, an exciting first thought leads to a dead end, such as a concept already widely established or previously discredited. In such cases, you need to either restart the process of searching for an idea or find interesting wrinkles of uncertainty in the topic at hand. It is important not to become frustrated or discouraged if you do not strike gold during the first attempt. Usually, the best ideas are those that are carefully developed over time. Fortunately, the very process of probing a topic familiarizes you with the terrain of knowledge through which you have to navigate, regardless of the eventual outcome. When you finally encounter an idea, its sophistication will reflect the great amount of thought you have invested. Ultimately, the key to formulating a great project idea is to *start thinking about it early.*

Passion, Research and Communication

The process of hunting for an idea varies from person to person and from discipline to discipline. Some students spend days in libraries absorbing a plethora of information from a variety of fields; others delve into a topic already presented to them by a mentor; and there are also a few (especially mathematicians) who just sit and think. Unfortunately, there is no single protocol that prescribes steps A, B and C to arrive at a fabulous idea D.

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Despite these differences, however, all great idea searches share commonalities that are integral to the strength, allure and promise of a concocted research topic. These commonalities are *passion, background research* and *communication*.

This chapter will elaborate on these three components of formulating an idea and will offer a general approach that can maximize your chances of finding a research topic that both resonates with your passions and holds great potential to evolve into a meaningful and award-winning research endeavor.

Passion: Starting in the Right Direction

Successful research results when you take ownership of an idea that you are genuinely passionate about. The degree of your interest in the project topic determines the amount of personal investment you will allocate to the project throughout your research journey—the more investment, the more initiative you will take to explore the topic and the better your project will become.

Turning on Your Interest Radar

Though the majority of students do this automatically when they look for a research idea, it is never too much to stress the importance of choosing an idea in a field that motivates you to explore and discover. It is not enough to settle on a topic that you think will win the science fair if you do not have an intellectual attachment to it. Though some students find rewarding ideas by randomly browsing papers and books across various scientific disciplines, most of those who triumph in higher-level science fairs and other competitions start with well-defined interests in mind.

Instead of going out of your way to scavenge for ideas and overwhelming yourself with old science books and publications—in fact, before you start doing anything—*think*. Think about the science topics that give you goose bumps of excitement, that make you say "Wow!", and that entice you to find out more about them. What areas in science compel you to read, watch and listen further without being prompted by class requirements or by your teachers?

Some students have difficulty identifying specific science topics in which they are especially interested. They love science in general. Every aspiring scientist, however, is partial to certain areas, even if he or she does not realize it. All that is required to uncover hidden passions is a simple systematic introspection.

Practically, this means becoming more aware of how the choices you have made and are currently making dictate your scientific preferences—in short, turning on your *personal interest radar*. Conscientiously scan for traces of evidence in your daily life that hint at distinct fields of interest. Make note of the science books you read, your favorite science classes, the science-oriented activities you enjoy, the Discovery or Science Channel shows that grab your attention, and even your future career aspirations. Carefully ponder your

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life up to now: which science topics absorb you the most? Furthermore, ask yourself why you are interested in these topics. Do you hope to cure a disease, alleviate the world's energy crisis, understand the origin of the universe or rationalize patterns of human behavior? Only by unearthing the roots of your interests can you be truly motivated to pursue research.

Note: Even though considering your future career goals can help you pin down your scientific passions, do not be constrained by them. It is perfectly fine for your science interests to deviate from your intended future career (which may change with time). For example, just because you want to be a doctor does not mean you need to work in a molecular biology lab (though, as was mentioned in an earlier chapter, research experience can help you decide upon your future career). What matters now is sifting through your daily activities and interests to find your true scientific passion(s).

> "I've always been interested in animal behavior and the delicate interplay between environment and ecological function. I have been fortunate enough to have spent all of my summers in the Catskill Mountains of upstate New York. My father and aunt encouraged my adventures into the forests, and would even aid me in my early specimen collection (frogs, newts, bugs and the like). I never called these outings a "science," but after taking several high school science classes and realizing that a laboratory course of study did not pique my interest, I went back to doing what I know."
> **Alexis Mychajliw:** *Finalist, Intel Science Talent Search; Cornell Class of 2012*

> "I believe students should first select their major area of the investigation (i.e., heredity, alternate fuels, molecular biology, informatics, etc.). We then discuss what they can possibly do given their interests, academic backgrounds, knowledge, time commitments, available equipment, etc. I have found over the years that when I make the initial suggestion (because I find the topic very interesting) very often the student will lose interest in the topic because it wasn't their area of interest from day one."
> **Nevin E. Longenecker:** *Veteran Research Teacher and creator of the Research Program at Johns Adams High School in South Bend, Indiana*

Fine-tuning Your Interest Radar

Once you are confident about your selected field(s) of interest, narrow down your preferences to particular topics and subfields. If you are interested in cancer research, what exactly is it about cancer that fascinates you? Molecular defects in the cell cycle? Genetic profiling? Drug screening? You may not have reached a stage where you can specify in detail the research that you want to pursue. In this case, try to recall and search for the cutting-edge topics in your field(s). Most importantly, go to online databases of research institutions such as the National Institutes of Health, the Howard Hughes Medical Institute, NASA, the Max Planck Institute and university research departments. On those websites, search for your general fields of interest and browse through each lab's research in the field to narrow down topics and spark new ideas. The wealth of ongoing research at these institutions provides a panoramic view of the leading research efforts in your fields of interest. These databases give you

a sense of the big and small questions scientists are currently tackling, and will help you orient yourself in the vast, interweaving tapestry of the field so that you can make informed decisions about your eventual research focus.

> "I became very interested in human behavior after learning about game theory in AP microeconomics. I had also read Richard Thaler's *The Winner's Curse* and Stephan Meier's *Economics of Non-Selfish Behaviour* and was curious as to why people donate money, a seemingly irrational action in the world of economics. I wanted to apply the different theories of why people donate to the real world, and chose to look at donation behavior in the context of public libraries..."
> Xiaomeng Zeng: *Finalist, Intel Science Talent Search; Harvard Class of 2012*

Background Research: Foundations for Your Central Question

Regardless of whether you narrowed down your specific research topics through the steps above or whether a mentor provided you with an idea to start with, background research is indispensable for you to take ownership of your work and generate your own questions. If you followed the advice above, then you already have a good start on background research. The purpose of background research is to identify *gaps in knowledge, unanswered questions* or *contested theories* for you to investigate in your own novel project. Your goal at this stage is not yet to become an expert in a given research topic. Technical language will present a barrier to your full understanding, but you do not need to understand every unfamiliar term to apprehend the big picture.

Zoning in on Radar Targets

Returning to the interest radar analogy, the next thing you have to do after selecting your research focus is to recognize and target the central question(s) you want to tackle in your project. The best way to approach this is to read background material with a critical mind. Just like reading the passages on the SAT or ACT, read actively by summarizing main points and asking questions (indeed, doing background research may actually help you perform better on critical reading sections of these standardized tests). Enumerate the knowns and the unknowns of a topic. What is missing in the puzzle? What is confusing to you? What are scientists trying to *answer, explain* or *support?*

The questions you ask during your background research contribute to the process of formulating project ideas in two ways. First, mentally probing the information strengthens your curiosity about the topic, thus motivating you to research more and generate more questions. Second, the very questions you formulate now can potentially become the central question, the impetus of your research. Do not yet concern yourself about the feasibility or possibility of answering the questions, and avoid discarding your questions prematurely. Presently, the focus is to engage your mind and to ask as many questions as you can. Al[illegible] record your questions and ideas immediately after you think about the

Finally, do not merely understand the reading. *Synthesize* it. Like completing a jigsaw puzzle, piece together diverse perspectives and ideas from different sources and build a comprehensive picture of the topic. Play around with the information available: Look for parts that do not fit, parts that contradict each other. Develop your own thoughts, hypotheses and explanations about a problem within a reasonable context. Immerse yourself in the topic while examining it from many different angles.

> "Doing background research on ALS, I noticed an unanswered question in published papers. There had been several suggestions implicating a splicing defect in ALS pathogenesis, but definitive data had never been obtained in genetically affected mice or humans. Based on these suggestions...I decided to search for a splicing defect in gene targets of the splicing regulator Nova, an RNA binding protein that is targeted in human motor disease."
> Alicia Darnell: *Second Place, Siemens Competition; Best of Category in Medicine and Health, Intel International Science and Engineering Fair; National Finalist, Junior Science and Humanities Symposium; Yale Class of 2012*

Sources for Background Research

One of the most popular repositories for general knowledge is Wikipedia. While you should never take the content on Wikipedia for granted, the online (and universally editable) encyclopedia can serve as a first stop in your background research. Generally, articles in Wikipedia highlight the most important aspects of a topic while providing a concise overview of the topic as a whole. Use Wikipedia to familiarize yourself with the field the first time around and allow the information presented to prompt questions so that you can look further into the content in other, more reliable, sources. An additional use of Wikipedia is the list of sources at the bottom of the page, which can direct you to journal articles, books and other websites. Such references can be very useful, especially when you do not know where to start your background research.

Most of your scientific research however, should be based on articles and papers in peer-reviewed journals and scientific magazines. These publications provide reliable and current reports of top-notch research happening around the world and serve as archives for significant work done in the past. If your topic belongs to biology, chemistry, psychology or related fields then PubMed *(http://www.ncbi.nlm.nih.gov/pubmed/)*, a publications search engine maintained by the U.S. National Library of Medicine, is an essential research tool. For other fields in science (biology as well), well-known journals such as *Nature, Science* and the *Proceedings of the National Academy of Sciences (PNAS)* showcase the leading national and international research efforts across all disciplines. If you want a summary and an evaluation of the pivotal research advances accomplished over the years in a certain field, then review journals such as the Nature Reviews are quite useful. For a lay explanation of scientif[illegible]ances, popular science magazines such as *Scientific American* and *Popular* [illegible]*ce* offer clarifying

insights into otherwise complex subjects. Even Dr. Leroy Hood, who is famous for inventing the automated DNA sequencer among other valuable devices, credits a 1956 article in Scientific American with piquing his interest in molecular biology (that same year, he competed in the Westinghouse Science Talent Search). Beyond abstracts, full access to articles published in these journals unfortunately requires subscription. Generally, libraries and even some schools subscribe to these journals and make them available to their members, so ask around for people and places that can help you gain access to such a wealth of information.

> "After my mentor gave me a protein to work with and a technique with which to analyze it, I spent many hours on PubMed reading essentially and tangentially related papers and thinking about how they fit together. I kept my preliminary results at the back of my mind, and eventually started to relate them to observations in the literature."
> Kelley Harris: *Third Place, Intel Science Talent Search; Semifinalist, Siemens Competition; Harvard Class of 2009*

Communication: Shaping and Polishing Your Ideas

Since science research is highly collaborative, formulating great ideas requires exchanges among scientists. Communication with researchers who are experts in your field of interest can provide valuable insights into your ideas.

One of the crucial steps that many students overlook in formulating project ideas is discussing them with peers and experts in the field. There is no danger in jeopardizing the authorship of your idea while communicating it to someone else. In fact, you probably formulated your ideas by reading other peoples' thoughts presented in the publications you have read, so talking with another person is merely an extension of the intellectual exchange that is so fundamental to developing project ideas.

Also, there is no need to fear that your thoughts and opinions might sound foolish and inadequate to an accomplished scientist. First of all, no one expects high school students to possess the same amount of knowledge of a field as researchers with years of experience. Secondly, proposing your own views and asking questions about a complex research problem show that you have properly thought about the problem.

When talking to a mentor or another scientist, there is no need to have a concrete idea in mind. Having a firmer grasp of the progress and advances of a certain type of research, a professional research scientist can often direct you to current problems and questions in the field. In most cases, this is what happens: A student finds a mentor in a lab whose research the student is interested in. The mentor and the student discuss possible projects, after which the mentor suggests a problem for the student to explore. It is then up to the student to take the initiative to formulate hypotheses and ideas about the problem.

This does not mean that you should look for a mentor to spoon-feed you with a project topic. Keep in mind that ultimately your own investment and passion toward the research you do will determine your project's success. Therefore, be sure that you have done background research before contacting a scientist. This will foster a two-way exchange of ideas rather than a meeting in which somebody else tells you what you should do for research. If you meet the scientist in person, always have a piece of paper and pen ready to record insights and information that will help you. Finally, ask for supplemental reading material regarding the topic of discussion. The expert has a better notion of the information that is most representative of the field and most appropriate to engage the thoughts of a novice.

Conversations with experts are an invaluable opportunity for you to further develop your ideas and gain helpful advice from experienced researchers.

> "Once I'd extended some old questions into questions about my own results, I talked to my research advisor about the connections I was seeing and what I wanted to know about my proteins. She helped me design an experiment that would provide some answers."
> Kelley Harris: *Third Place, Intel Science Talent Search; Semifinalist, Siemens Competition; Harvard Class of 2009*

The Serendipity of Accidental Ideas: Being Observant, Alert and Inquisitive

In the fields of observation chance favors only the prepared mind.
Louis Pasteur

From time to time, magnificent ideas spring from fortuitous events that occur in the right place at the right time. In fact, many seminal discoveries in science (such as the discoveries of penicillin and carbon nanotubes) were results of unintended consequences of carefully designed experiments. Though some attribute these ideas and discoveries to pure luck, much more than luck is involved in transforming these accidents into scientific advances.

Accidental scientific epiphanies are certainly not born out of a vacuum. Scientists do not idle around waiting for an idea to form spontaneously. Rather, ideas form through a process similar to that which created the first amino acids (according to the seminal experiment by Miller and Urey); the conditions had to be right for the chance electrical discharge to create the complex structures. Scientific "accidents," therefore, are not really accidents at all, but additional sharp observations that yield novel and different insights about a subject. Without the knowledge and the alertness to recognize peripheral or unintended results as important manifestations of science, you cannot transform an accident into a visionary idea or discovery even if it could be the most important finding in the history of science.

Accidental ideas are rare, so you should not rely upon the gift of chance, but when they occur, they tend to be the most exciting and ground-breaking

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of all. Therefore, it is important in your process of developing, polishing and testing your ideas to keep an open mind, and always be alert, observant and inquisitive about your research environment. These qualities compose the mental net that catches the fortunate accidents that can slip away unnoticed by an inattentive problem solver.

> "I was using thin-layer chromatography to track the progress of a reaction. I took some pictures of the TLC plates to put on my display board. When I printed the pictures, I accidentally pushed a button in Photoshop and one of the chemical spots turned blue and the rest stayed black...I learned later that this button emphasized colors that the camera could see, but my eyes could not. When searching for my next research project, I thought back to the weird incident and tried to figure out what it might mean. After doing some quick experiments, I realized that the chemical I was studying was fluorescent and the TLC plates were so much brighter than the chemical spot that my eyes could not see it, only the camera picked up on it. I started studying more fluorescent chemicals to see if I could detect the fluorescence with a digital camera. This formed the qualitative aspect of my project—I discovered that digital photography could help identify some chemicals on a TLC plate."
> Amber Hess: *First Place in Chemistry, Intel International Science and Engineering Fair; Finalist, Intel Science Talent Search; Semifinalist, Siemens Competition; MIT Class of 2009*

The Characteristics of a Good Topic

A good research topic does not simply aim to replicate what has already been established. It does not solely aim to report, but to build upon previous work and pave the way for future explorations. In other words, it must refer to research done in the past and suggest ways of extending the given question in the future. Exemplary research topics often.

- add to a previous model or paradigm;
- challenge a standard model or paradigm;
- clarify or explaining a phenomenon;
- discover something new;
- optimize an existing practice or technique;
- develop a new technique; and/or
- apply knowledge in novel ways.

These characteristics do not necessarily become apparent right away. Through unexpected twists and turns and the discernment of an inquisitive mind, projects can take exciting directions and make seminal contributions to our current scientific knowledge. In sum, great research ideas originate not from a desire to win a science competition, but from a genuine and heartfelt interest to learn, explore and discover.

> "Whatever you do, do something that interests you. It is so much easier to put in the time and energy necessary to do well at these competitions if you are passionate about what you are studying, and your passion (or lack of it) certainly comes across when you write and present your research. Take the initiative to do work that may not necessarily be expected of you. That is what these research programs are

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> about: using your time to do something extraordinary that no one would expect of a high school student. You will get out of the experience what you put into it. Take advantage of the chance to forge connections with your teachers and other researchers. I am still great friends with my research teachers, and have been able meet many individuals who I hope to contact as I continue my work on advocatin for our nation's veterans. Performing high-quality research as a high school stude is a powerful opportunity that I would certainly say is the best thing that happen to me in high school."
> Ilana Rice: *Second Place, Young Epidemiology Scholars Competition; Finalist, Junior Science and Humanities Symposium; Semifinalist, Intel Science Talent Search; Barnard Class of 2013*

Take-Home Points

- Successful project ideas take time to develop, so allow ample time for brainstorming.
- All great ideas derive from
  - genuine passion towards the topic;
  - effective background research; and
  - active communication with experts in the field.
- Alertness, curiosity and open-mindedness are crucial for catching serendipitous ideas.
- An exemplary project topic adds something new to an existing field and prompts future investigations.
- Visit the Archimedes Initiative *(www.archimedesinitiative.org)* to see the topical videos, "Choosing Your Experiment" and "Literature Search."

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- To learn more about the importance and qualities of exemplary student-mentor relationships, read a feature article in *Nature* available (for free access) online: Lee, A., Dennis, C. and Campbell, P. *Nature's* guide for mentors. *Nature* 447, 791-797 (2007).

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The Importance of Keeping a Logbook

Writing is like driving a car at night. You never see further than your headlights, but you can make the whole trip that way.
E. L. Doctorow

On the most basic level, a logbook is a journal in which you record every step of your experiment as you conduct it: your lab notebook is the official record of what you did; however, any experienced laboratory researcher will tell you that a logbook has so much more to offer. Your logbook is a good place to brainstorm ideas and to record questions as they crop up as well as the answers when you find them. Accurate recordkeeping can be a huge asset to you as you conduct research, to your mentor and colleagues long after you have moved on from the lab and to your performance in competitions. Preparing your logbook will also be useful practice for the many laboratory classes that you will take in college, should you continue studying science.

Ideally, your logbook will be written in pen and organized by date, containing an entry for each time you worked on your research project. It is surprising how quickly you may forget aspects of your experiment if you do not write them down. Standard practice dictates that you should never rip out any pages from the notebooks, nor leave blank pages. Any errors should be crossed out with a single line (never white them out). If you have typed up step-by-step protocols it is a good idea to paste the print-out in the notebook for future reference. Creating spreadsheet templates which automatically perform calculations for you can be useful. These can be easily printed out for your logbook and modified when necessary. Also, for the purpose of science competitions, it is often a good idea to include photographs in your lab notebook of equipment used and of any visual results. If you have many images, such as microscopy images, you may want to include these in a separate three-ring binder as a supplement to your logbook; however, it is

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important that everything be accurately labeled and dated.

In addition to explaining exactly what you did, you should also use your logbook to catalog practical information for future reference, such as detailed specifications of your experimental materials. For example, when you use a particular antibody or chemical solution, it is often a good idea to tape the product insert right into your lab notebook. This method saves you time and assures that you will have all the important facts about the product accurately recorded. A piece of information you may not expect to be useful could turn out to be critical later on. For example, if you have been getting great results with an antibody from a particular company and a particular lot number, you will want order more from the same lot. Likewise, if your experiments start to fail you may need to look back to earlier steps that you have recorded in your logbook to figure out what went wrong. Since you will know what you have tried already, you can use this to make adjustments and refine your techniques. Your lab notebook will help you to communicate precisely about the situation with your mentor. Diligent record keeping will assure your mentor that you are confident in the work you have done. If you cannot confidently tell your mentor how you performed a particular procedure, and that procedure failed, he or she will almost certainly ask you to repeat the task. Thus, in all of these situations, and countless others, the time and effort you invest in keeping accurate records will save you substantial time and effort in the future.

Alexis Mychajliw, who conducted ecology field research, created her own fieldwork note sheets to be used in collecting the specific data points she needed. Alexis caught hundreds of dragonflies and damselflies and kept records of where they lived, what behavior they were performing and what species and gender they were. For Alexis' research, accurate and detailed records were especially important, because slight variation in environmental conditions were likely to skew her results and conclusions: "It was exceedingly important for me to keep accurate records of every field outing, including menial things such as temperature and weather conditions, because since I was working in an actual environment, I could not take any one variable for granted... my entire thesis was based upon the movement and response of a certain fragment of the total sample size." Whether you realize it or not, the details matter and you should record any irregularities that occur as you conduct your experiments. These may become important in understanding your results later.

If you are not yet impressed by the many benefits your logbook can offer you, consider what the logbook means to your mentor. He or she has been generous enough to share his or her time, expertise and research grant dollars with you. In exchange, it is only courteous to make sure that at the end of your time in the lab your mentor has written record of what you did. Your mentor will expect you to document your work thoroughly and will appreciate the

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effort you put into your lab notebook. Do not frustrate or disappoint your mentor with shoddy notes! A few years down the road, another person in your lab may need to use your logbook to try to reproduce your results. Carefully documenting what you have done will also work to your advantage if you plan on trying to get your research published.

Dayan Li, who won top honors at the Intel International Science and Engineering Fair (ISEF) can attest to the critical importance of the logbook. He notes that while papers and other publications are forms in which you *communicate* your research, the logbook is your actual *"immortalized research."* As Dayan points out, the logbook is a critical supporting document to your poster display, because it documents every step of your journey and should contain every detail of your work. While your poster presents the work as a whole, the logbook is an important indicator of how independently you worked. You should state clearly in your logbook which parts of your project you did and also acknowledge which parts you were helped with. Science fair judges, who are scientists themselves, will be interested in seeing how thoroughly you documented your work since this allows others to reproduce it in the future.

For many reasons, diligent recordkeeping in your logbook is an essential part of your ability to conduct successful laboratory research. The time you invest creating the logbook will pay for itself many times over. Not only will you make life easier for yourself by keeping accurate notes, you will also seize an important and relatively easy opportunity to impress your mentor and others evaluating your research, such as competition judges. By putting together an excellent logbook, you will also guarantee that your research is preserved in its most original, authentic form for future reference by yourself and others.

Take-Home Points

- Keeping a thorough record of your research is valuable for you, for your research and for your mentor.
- Documenting your work will allow you to make sure that you understand what you are doing as you conduct research and that you remember what you did months ago. Keeping a logbook takes time, but it is critical for interpretation of results, troubleshooting and for others to replicate your work. Good scientific practice dictates that your research should be able to be independently replicated by others.
- A logbook is also critical for your mentor after you have left the lab and may help your contributions to be recognized if your data is published in the future.