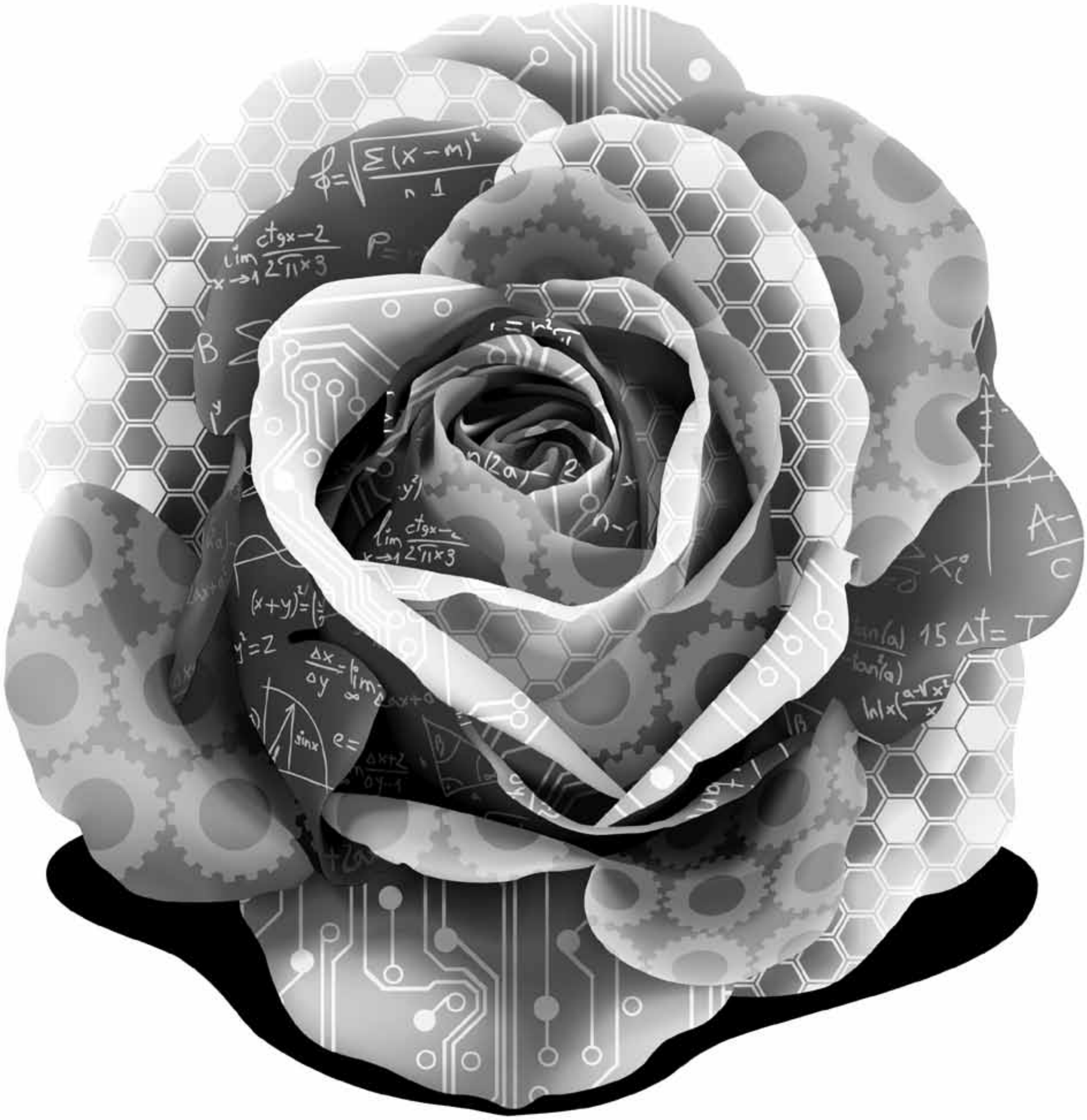
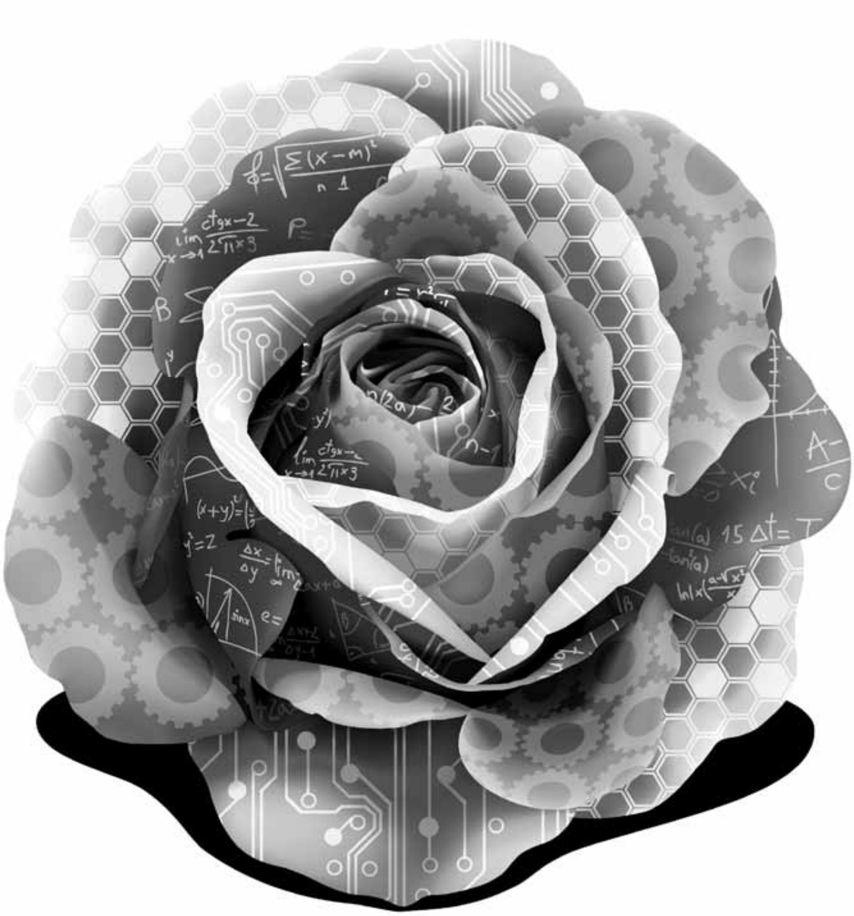


STEM

STUDENT RESEARCH HANDBOOK



STEM

STUDENT RESEARCH HANDBOOK

Darci J. Harland

NSTApress
National Science Teachers Association
Arlington, Virginia

NSTA press®
National Science Teachers Association

Claire Reinburg, Director
Jennifer Horak, Managing Editor
Andrew Cooke, Senior Editor
Judy Cusick, Senior Editor
Wendy Rubin, Associate Editor
Amy America, Book Acquisitions Coordinator

ART AND DESIGN
Will Thomas Jr., Director
Joseph Butera, Senior Graphic Designer, Cover and Interior Design
Mary McCubbins, Group Icon Illustrator

PRINTING AND PRODUCTION
Catherine Lorrain, Director

NATIONAL SCIENCE TEACHERS ASSOCIATION
Francis Q. Eberle, PhD, Executive Director
David Beacom, Publisher

14 13 12 11 4 3 2 1

Library of Congress Cataloging-in-Publication Data
Harland, Darci J., 1972-
STEM student research handbook / by Darci J. Harland.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-936137-24-4 (alk. paper)
1. Research--Study and teaching (Secondary) I. Title.
Q180.A1H37 2011
507.1'2--dc23
2011023245

eISBN 978-1-936137-41-1

CONTENTS

CONTENTS

CHAPTER 3
Background Research and Note Taking

CHAPTER 4
Writing Hypotheses

CONTENTS

CONTENTS

CHAPTER 8
Graphical Representations

CHAPTER 9
Inferential Statistics and Data Interpretation

CHAPTER 10
Documentation and Research Paper Setup

CONTENTS

CHAPTER 11

Writing the STEM Research Paper

CHAPTER 12

Presenting the STEM Research Project

DEDICATION

This book is dedicated to all my former students. I am indebted to each of you. Your willingness to work hard, with minimal grumbling, has been an inspiration. My goal was never to turn each of you into STEM researchers but rather to help you gain a clear understanding of how scientific knowledge is acquired. I thank you for putting up with my inadequacies and my pat sayings and for trusting me when I told you the hard work would pay off.

PREFACE

Our nation's success depends on strengthening America's role as the world's engine of discovery and innovation. … CEOs…understand that their company's future depends on their ability to harness the creativity and dynamism and insight of a new generation. And that leadership tomorrow depends on how we educate our students today—especially in science, technology, engineering and math.

—President Barack Obama, September 16, 2010 (Sabochik 2010)

The importance of improving science, technology, engineering, and mathematics (STEM) education has become a popular topic in recent years. It is clear, however, that the STEM education that today's high school students receive rarely mirrors what individuals in STEM careers actually do. Students are focused more on memorization than on identifying problems and finding ways to solve those problems. *STEM Student Research Handbook* engages students with the same inquiry skills used by STEM professionals. The handbook supports students as they practice skills of designing and conducting experiments and analyzing and presenting their findings.

I believe that the primary reason STEM educators do not include student-directed research as part of their curriculum is that they themselves have limited experience in this area. My goal in writing this book was to provide a practical resource that teachers and students can use to become actively engaged with topics that interest them as they are guided through the stages of a long-term research project. I hope that this handbook bridges a gap between STEM professionals and classroom teachers by providing a resource that will help students experience learning in the way scientists do, by doing research.

My experience is similar to that of many other teachers who at one point decide to implement a research component in their classrooms. Having designed and completed only one science experiment on my own as an undergraduate and only educational research as a graduate student, I was uncertain about my ability to lead high school students in performing research. When I received the first set of student research papers, it was obvious that I had to make changes in how I supported students through the research process. Over the years, as I identified resources, modified deadlines, and developed activities that helped students to implement the scientific process for themselves, I saw student research papers improve greatly. This handbook is a compilation of years of work, lessons learned from mistakes, and the good advice of other teachers and STEM professionals.

The handbook addresses the two major aspects of conducting research: planning and conducting experiments and then analyzing and communicating results through writing. First, the handbook provides a structure for STEM teachers to use as they work through the stages of the research process with their students. There is enough detail here so that even teachers who have never designed an experiment on their own can feel comfortable guiding students through theirs. Second, large segments of the handbook address the writing (aka language arts) issues involved with research. I believe that STEM teachers who are not specially trained in writing will find the writing instructions here to be invaluable. As a science teacher who has also studied and taught English, I have been able to help STEM students see the importance of communicating their results through effective writing. Whole chapters in this book cover note-taking techniques, proper documentation of research papers, and presentation preparation. Sadly, in-depth writing advice is commonly missing from other books teaching students how to conduct research.

The opportunity to design and conduct an experiment and then present the findings at local symposia has changed the lives of many of my high school students. They learned to take the initiative for their own learning, and many chose to enter STEM-related fields when they went to college. As I got better at leading my students through STEM research projects that they were really interested in, they started winning awards at the competitions, bringing home top prizes. In 2004, I was awarded the Sigma Xi (Illinois State University/ Illinois Wesleyan University chapter) Outstanding Science Teacher Award for my students' contributions to these competitions and for encouraging other local teachers to implement long-term research projects. Most rewarding to me, however, has been that my students actually performed the exciting research process from beginning to end and acquired better understandings of how STEM knowledge is advanced. That experience is completely different from listening to a lecture, observing a STEM professional on the job, or even performing hands-on labs that someone else designed.

Reference

Sabochik, K. 2010. Changing the equation in STEM education. The Whitehouse Blog: *www.whitehouse.gov/blog/2010/09/16/changing-equation-stem-education.*

ABOUT THE AUTHOR

Darci J. Harland, PhD, a former biology and English teacher, is the assistant director of research at the Center for Mathematics, Science, and Technology (CeMaST) at Illinois State University. Her educational experiences range from undergraduate and graduate education and biology courses, to high school and middle school science and English courses. Her research interests include the long-term impact of scientific research performed by high school and undergraduate students, the influence of personality on online and face-to-face classroom participation, the use of digital media as a tool for reflection, and the level of inquiry in one-to-one laptop classrooms.

ACKNOWLEDGMENTS

I would like to thank a number of individuals for the support and assistance they provided through the evolution of my life as well as the evolution of the *STEM Student Research Handbook*.

First of all, I am grateful to my parents, Craighton and Linda Hippenhammer. I am extremely appreciative for having been raised in a home that cultivated a wonder for the amazing world we live in and encouraged me to learn as much about it as possible. I am thankful for my husband, Craig, and my two boys who supported me during the long hours of writing.

A special thanks to the staff at the Center for Mathematics, Science, and Technology (CeMaST) at Illinois State University: Dr. William Hunter, whose encouraging words kept me writing when I wanted to quit; Ydalisse Pérez, Nicole Enzinger, and Dr. Jeff Helms, who contributed writing and conceptual support in areas where I am weak; Mary McCubbins for her expertise in graphic design; and Sara McCubbins and Amanda Fain for their editing.

Thanks also to Dr. Randall Johnson at Olivet Nazarene University, who modeled natural inquisitiveness whenever he asked, "How does it know?" I thank him for providing my first opportunity to conduct STEM research as an undergraduate in his ecology course. I now have an appreciation for the restraint he displayed when he answered my questions with more questions. He is an exemplary teacher.

Last, but not least, I am grateful to Suzanne McGroarty, the veteran teacher whose shoes I attempted to fill after her retirement. She inspired this book! I so appreciate "the McGroarty legacy" and the opportunities I had to improve myself as a teacher because of it. Sue's love of science, genuine concern for her students, and positive attitude as a career-long teacher truly have made her an inspiration and model to STEM teachers everywhere.

INTRODUCTION

To the Teacher

If you are a high school STEM or other kind of science teacher, you most likely already understand the value of having students *do science*. However, even with our best efforts to include inquiry in our teaching, the logistics of organizing learning experiences that encourage students to ask questions that they themselves answer is overwhelming. If you have considered, or are considering, implementing student-centered, long-term research projects, my guess is you have a few questions, such as, How do I monitor students doing various projects, at various stages? What if students want to design an experiment on a topic I know nothing about? What if the students get in over their heads? Can I include long-term research projects as part of my curriculum and still cover the required content? How can I ask my students to design an experiment if I have never done one? Questions like these are enough to send any teacher into a tailspin and to drop the idea forever. However, I am here to tell you, it can be done, and this handbook will show you how.

Incorporating Research Into the High School Science Curriculum

There are several ways that teachers, departments, and schools incorporate long-term research projects into the science curriculum. Sometimes it starts with a single teacher helping a few ambitious students who perform their own research before and after school. Other teachers add a long-term research project to an existing course and then work diligently to balance the content they need to address with the support students need to complete their projects. Some science departments systematically include research components throughout the curriculum, so that upon graduating, students have conducted multiple research projects at varying levels of difficulty. Sometimes a school is able to dedicate an entire course to student-centered research or provide a similar experience in summer enrichment opportunities. This handbook was written for any of the above scenarios.

Whatever your situation, I advise you to first decide how much time you want to dedicate to a research project and then decide on deadlines. As with any other unit plan, start with the end in mind. When do you want to have the research project (either a paper or poster presentation) in your hands to grade? Once you have determined the final deadline, set deadlines to assess your students along the way. This handbook provides support in the construction of deadlines on several fronts. Appendix A is a sample checklist for developing deadlines. More indirectly, there are cues for you throughout the handbook. Although I wrote the book in language directed to your high school students, you will find references to "your teacher" throughout. I intended these as cues for you. I use phrases such as, "Your teacher may ask to see…" or "Your teacher will prefer either ___ or ___" as a prompt for you to discuss your requirements with your students. These cues suggest options of what sort of assessments to make along the way. I suggest you give grades throughout the length of the project, both formally and informally, to foster the concept of a journey of research, rather than giving a single grade to a final product.

Next you will need to decide how you want students to work—individually, in pairs, or in groups. On one hand, having students work individually simplifies the research process because each student performs each stage of the process individually and can choose a topic that is personally meaningful. For you, of course, individual projects will increase the total number of projects you must monitor and assess. On the other hand, allowing students to work in groups reduces your grading, but it does introduce other challenges—for example, students will often need guidance from you on how to divide the workload. (Throughout the handbook, a group icon—see p. xxvi—will signal tips for how groups might work together to accomplish the task at hand.) If you do choose the group route, I suggest that throughout the process you provide time for group members to frankly discuss their strengths and weaknesses, evaluate themselves and each other, and assign specific tasks to each individual in a signed contract that you also sign. Each group contract should cover the background research (Chapter 3), proposal (Chapter 5), data collection (Chapter 6), paper writing (Chapter 11), and presentation (Chapter 12) stages of the research project.

Using Outside Mentors

You may want to consider encouraging or even requiring your students to find a STEM mentor within the research field that interests them. Even if you have no local university or STEM industry companies in the vicinity, students can search online for possible mentors and be mentored at a distance. Your role when students work with a mentor is that of coach: You ensure that students meet deadlines, conduct the scientific process themselves (as much as possible), and communicate with their mentors. Support from mentors in the field frees you from having to be a content expert on each of the student projects. However, you are also releasing control of the level at which students experience the scientific process, particularly if a student is physically working in their mentor's lab. It is possible that the mentor's research interests will truncate your student's interest in the topic or field of study. Students may not have the opportunity to develop their own hypotheses and research designs but instead will participate in research currently being completed. The experience would still be a rich one, and beneficial to students, but it will differ from the experiences of students who do not have mentors.

Students who find online mentors are more likely to develop their own experimental design, using their mentor as a content expert and someone who can help them determine an appropriate research design for what they want to study. These mentors—if they become invested and prove to be reliable—are invaluable and provide students with an understanding of the research process that they may not otherwise receive. In this handbook, I refer students to "your teacher," but in the section of this introduction called "To the High School Student" (which begins on p. xxv), I let them know that if they are working with mentors, some of the references to *teacher* may actually refer to their *mentors.* You will need to communicate clearly with students regarding the differing roles between you and their mentor.

Do not underestimate your ability to coach students through research projects without mentors. Students can have successful research experiences with you as their primary resource. Even if you have never conducted a research project from the planning to the presentation phase, the *STEM Student Research Handbook* contains the details to guide you and your students comfortably through the process.

STEM Writing

After your students complete their research project, most likely you will ask them to either design a poster displaying their research results or to write a paper. In either case, students will be writing to communicate their results. It is important that you do not give short shrift to the writing part of their projects. Although it is natural that teachers trained in STEM subjects would be more interested in the experimental techniques and experiences than in the final paper and the writing steps that lead up to it, *it is crucial that you allow the necessary time for students to take notes, write up their designs and results, and write the final papers in preparation for presenting their experiments to an audience.* This handbook gives you great support in these areas (see especially Chapters 3, 10, and 11).

When I was in high school, I learned how and where to find resources and use them to support my thoughts or ideas. This really helped me when I was in college and writing research papers.

—Student Researcher

It would also be a good idea to talk to members of your English department about the writing aspect of your research project. Ask them at what level they require students to write their first large report and how they teach the report-writing process. This information will help you determine how much help your students will need. You are most likely to receive support from your English teachers if you use the note-taking strategies and documentation style that they teach. Most high school students will have written reports prior to your class, but it is possible that the idea of keeping detailed, organized notes to be used in a paper with reference citations is a new concept to them. Perhaps they have not, up until now, had to use parenthetical citations within a paper and have simply listed references haphazardly at the end of their papers. You will do your students a huge service by helping them understand the importance of competent documentation.

The most important lesson I learned in completing a research project was the basic research skills such as using databases, taking notes, and using citations properly.

—Student Researcher

I chose the MLA (Modern Language Association) documentation style as the one for students to use. MLA style is what most high school teachers use with their students, and it is the first documentation style they are likely to encounter in college. I completely understand a STEM teacher's resistance to MLA style since scientific papers are never written in this style. However, it is more important for students at this stage to understand the principles behind documentation. If you plan on having your students present their research at local, state, or national fairs or symposium contests, be sure to refer to their guidelines regarding documentation style. Most competitions do not require a specific style, only that it is applied consistently and correctly.

Another significant skill students should learn while doing this research project is how to do quality background research both online and at the library. I suggest that you contact your school and local librarians for help in organizing resources for your students. Although your school and local libraries may not have current paper resources on particular STEM topics, librarians can offer a session with students to help orient them to databases the school has access to along with any interlibrary-loan agreements that are available to students. (The technology icon—see p. xxvi—is used throughout the book to highlight tips for using technology during the research process.) I also highly recommend that, if possible, you organize a full-day field trip to a large university library, particularly if students are not introduced to a university library as part of their English courses. The greater number of STEM scholarly resources available through academic libraries will be worth the effort.

The Proposal Process

I don't know if I ever really had an accurate understanding of the scientific research process before I did my own research project. I probably could've listed the steps for you, but until I actually did it myself I never really understood what it means in real life.

—Student Researcher

The first year I implemented research projects it became clear just how little students knew about applying the scientific method to their own experiments. My students could define the various aspects of an experiment, such as control, experimental groups, extraneous variables, and constants, but when it came to applying these concepts to their own research, they really struggled. I discovered that students need a lot of support in developing their research design. That's when I developed a proposal approval process (see Chapter 5). The proposal itself is quite an accomplishment for students, and the *STEM Student Research Handbook* supports them as they take small steps to reach a point where they can write a full research proposal. These steps include identifying questions they have about a topic, identifying possible independent and dependent variables, researching ways in which connections have already been made between them, and then writing a hypothesis to test their idea. The research design table in Chapter 2 will help students hone their ideas further. I encourage you to spend significant time on writing hypotheses and to preapprove them before students begin writing their proposals. Students' first significant grade should be the hypothesis.

Completing the research project was the first time I ever really learned on my own. The teacher wasn't putting the information in front of me to memorize, rather I had to do my own research and how much I learned was directly related to how much effort I put into the research.

—Student Researcher

I also strongly suggest that you have students revise their proposals until you are confident that the proposals show that students have thoroughly researched the topic, that they have accounted for extraneous variables, and that their research designs are detailed enough to convince you that the students have a good chance of being successful. I call this type of assessment "Do Until Accepted" (DUA) (see Appendix A). To make this work, I have two due dates. The first is when students are required to turn in their first draft and the second is a week or two later. On each of these drafts, I write comments to help students improve their research designs. I don't give students an actual grade (in my grade book) until I give my approval for them to begin their research. If they want to receive an A on this assignment, they have to meet both deadlines. Within this time span, they can rewrite the proposal as many times as it takes to get it accepted. Some students will rewrite it three times and others nine times. Students who missed one of these deadlines cannot receive higher than a B on the proposal.

Research Symposia and Science Fairs

I encourage you to seek out an opportunity for your students to share their research at a research symposia or science fair. Knowing that individuals other than their teacher will be viewing and assessing their work is a strong motivator for students. You can locate competitions easily by searching online. Even if you decide not to attend someone else's event, I highly suggest you have an open house one evening where students showcase their research to parents, administrators, and community members. You could choose to have judges or just allow individuals to visit and talk with your student researchers about their projects.

I was never one to put more into school work than what needed to be, but because I was doing the research project on my own, and we were taking it to the symposium, I was more interested in the work that I was doing. I cared more about what the outcome would be instead of looking at how much work was put into it.

—Student Researcher

My last piece of advice is to pay attention to the balance between how much control you have over student projects and how much choice you give to students. Although students need structure, feedback, and support, it is also important that they have ownership of their projects. This may mean that students will choose a topic with which you are not familiar. I encourage you to allow students to include integrated STEM projects, even if their choices make you uncomfortable. For example, a student may have learned how to use a specific piece of equipment in another STEM course and wants to use it as part of this project. Admit your vulnerability, and agree to learn along with your student. Guiding students through the research process can be the most rewarding aspect of teaching.

All too often in college and high school, students just regurgitate the knowledge of others over and over in papers and projects. But this, an actual research project, forced me to come up with my own ideas for an experiment and formulate my own educated conclusions with the support of other research.

—Student Researcher

Importance of Student-Centered STEM Research

The scientific method is a common introductory topic within all science curricula (Bereiter and Scardamalia 2009). However, it is well documented that just because students can describe the scientific process doesn't mean that they are able to perform scientific thinking or show productive inquiry skills (Ayers and Ayers 2007; Leonard and Chandler 2003; Tang et al. 2010). Therefore, without having gone through the scientific process themselves from beginning to end, students are unlikely to truly understand the nature of science, especially that the process of scientific inquiry is often nonlinear.

Authentic research experiences have the potential to provide high school students with the scientific reasoning skills desired by both high school and university instructors. Although some STEM classrooms use labs with procedures where students simply record the results, others use inquiry and problem-based learning (PBL). Research done in K–12 classroom shows that when teachers implement problem-based projects and inquiry-based labs, students not only learn the same content as in lecture-based units but also gain critical thinking and problem-solving skills (Drake and Long 2009; Tarhan et al. 2008; Wong and Day 2009).

PBL and inquiry should have an important role in STEM courses. Unfortunately, the common model is still teacher-centered (Taraban et al. 2006)—the teacher decides the topic that students will study and the teacher sets up the problem or question that students will answer. Although students may be engaged and learning about problem solving, they are not designing their own experiments to address problems that they themselves have identified. When students are in control of their own research, it increases motivation and creates a strong sense of ownership (Marcus et al. 2010).

Many high school curricula do not include long-term inquiry research projects in which students design and implement a lengthy experiment themselves (Leonard and Chandler 2003; Taraban et al. 2006). This could be why postsecondary science instructors find college freshmen to be lacking in basic scientific processing skills (ACT 2009).

Organization of This Handbook

The *STEM Student Research Handbook* was written to support you and your students in two areas of STEM research: planning and conducting research (Chapters 1–6) and doing statistical analysis and communicating the research results (Chapters 7–12). Here is a brief description of the contents of each chapter:

Chapter 1 "Beginning a STEM Research Project" defines research and provides ideas for how to generate and focus ideas for research topics. It also includes a section on safety and ethical issues in STEM research.

Chapter 2 "Research Design" introduces the components of a basic research design and defines key vocabulary terms such as *experimental groups*, *constants*, *quantitative data*, and *qualitative data*.

Chapter 3 "Background Research and Note Taking" helps students organize background research. It discusses how to identify reliable resources, provides two different ways to organize notes, offers tips for avoiding plagiarism, and cites helpful technology tools.

Chapter 4 "Writing Hypotheses" walks the student through the process of constructing a testable hypothesis.

Chapter 5 "Proposal Writing" guides students through the process of refining their research designs to a point where they can present you with a written proposal for their experiments that you find acceptable. This chapter also addresses some common misconceptions about scientific writing.

Chapter 6 "Organizing a Laboratory Notebook" introduces students to the essential contents of a laboratory notebook and provides tips about making the same kind of entries in their notebooks that STEM professionals make.

Chapter 7 "Descriptive Statistics" gives instructions for how to find measures of central tendency and statistical variability. It also presents additional calculations that can be performed on data once an experiment is complete.

Chapter 8 "Graphical Representations" describes various graphical representations for communicating data such as various types of graphs, plots, and tables. Graphical representations are organized by the type of data, either qualitative or quantitative.

Chapter 9 "Inferential Statistics and Data interpretation" introduces various mathematical tests that can be used to determine the statistical signifigance of data. The last part of this chapter helps students interpret their data.

Chapter 10 "Documentation and Research Paper Setup" introduces the basic concepts behind documentation and provides a brief introduction to MLA style documentation.

Chapter 11 "Writing the STEM Research Paper" walks students through the writing of the parts of a scientific research paper.

Chapter 12 "Presenting the STEM Research Project" supports students who are asked to make oral presentations about their research.

Organization of Individual Chapters

Each chapter begins with a list of Key Terms that will be introduced in that chapter. The Learning Objectives at the beginning of the chapter will help you determine what it is that your students should know after reading and working through the chapter. Each chapter concludes with Chapter Questions and Chapter Applications. The Chapter Questions align with the Learning Objectives; you might assign them for students to complete as homework or use them to stimulate a class discussion. The Chapter Applications summarize how the ideas taught in the chapter apply to the student research project, including how they apply to the next step of the project.

To the High School Student

I wrote this research handbook for students like you who are being asked to conduct a large-scale research project. In your class, the research project may be part, or even all, of your grade. It is possible that this project is the biggest, and the most long-term, assignment you have ever been asked to complete. Take heart! *STEM Student Research Handbook* is designed to support you in two major research areas: first, it will help you plan and conduct your own experiment (Chapters 1–6) and, second, it will help you analyze and then communicate your results (Chapters 7–12).

Your teacher may choose to introduce you to STEM research in a variety of ways. This handbook addresses many of them; however, be sure to take the advice of your teacher and follow any additional guidelines given to you regarding this research project. Some of you will be asked to pair up with a mentor—either a university researcher or an individual in industry—in addition to having the support of your teacher. Therefore, there will be times in this handbook when I use phrases such as, "Your teacher…." If you are working with an out-of-school mentor, however, substitute the word *mentor* for *teacher.* Ask your teacher whom you should report to for specific aspects of the project.

The fields of science, engineering, mathematics, and technology (STEM) require individuals who are creative and flexible and have a sense of humor about themselves and the world around them. The best way to learn about this exciting side of research is to experience it yourself rather than having it explained to you. I hope that as you begin the journey of developing your own research project, you will see how applicable and exciting research can be and how absolutely critical it is for researchers (including you!) to be creative as well as rational.

Group and Technology Icons

Group icon

Throughout the *STEM Student Research Handbook,* you will find two important icons. The first is the group icon that highlights tips geared to students who are working in pairs or small groups. Overall, the handbook is written with the assumption that most of you will be working individually. Sometimes, however, teachers decide to have groups of students work together on research projects. The group icon is placed next to suggestions regarding how groups can work well together, share research responsibilities, and remain accountable to one another.

Technology icon

The technology icon highlights tips in the text for using technology during the research process. The internet has truly made our world more global, with access not only to mind-boggling amounts of information but also to free Web 2.0 tools to help find and organize research and streamline collaboration among people working together. On this "read-write-web," users can mark up web pages, share files, photos, and create their own interactive spaces. The technology icon brings your attention to specific ways that technology might help you at specific times during the research journey. There are amazing free online tools that can help you retrieve and organize information from the internet and collaborate virtually with others.

You will also find suggestions of specific hardware or software technology that would be helpful during the analysis phase of research. At that point, you will most likely need either a graphing calculator and/or spreadsheet software. Find a way *now* to have access to either one of these technologies so you aren't scrambling later to come up with them. Always communicate with your teacher regarding how much and which technology he or she wants you to use.

Using Technology as Part of the Research Process

Below are introductory descriptions of three basic Web 2.0 tools that will be referred to often in this handbook. If you have a basic understanding of each one, you can make an informed decision about whether or not to use them during the research process.

Wikis

Wikis are websites that allow their members to have web pages that can easily be edited using "what you see is what you get" (WYSIWYG) editing tools. By clicking on the edit button located at the top of each page, a member can type in text, insert images, embed videos, upload documents, and provide links to pages within the wiki or to external web pages. After hitting save, the member has created a web page! If the creator of the wiki wants it to become a place of collaboration, he or she can invite others to become coeditors. Now group members have a place to edit text, add content, and make comments—all on the same web page. *Wikispaces.com* and *pbworks.com* are two sites that are often used for educational purposes.

But that is only the beginning. Using the "history" and "discussion" tabs at the top of each page is what makes a wiki unique. The history tab keeps a detailed record of each edit made to that specific page. The edits are listed by date and indicate the member who made the edit. Edits can be viewed, and added text will be highlighted in one color and anything deleted will be highlighted in another color. By clicking the link titled "revert to this version," edits can be overridden. The discussion tab allows members to discuss the construction of the page. For example, one student might start an outline on the actual wiki page and then also start a discussion "behind" the page, asking other members to add to specific parts.

If you are working on your research project with other students, the wiki can become the unifying place where you are able to meet online as well as the one place where everything is located. You can post schedules and deadlines, discuss protocols, share online sources (although social bookmarking sites do this better), or begin posting drafts of the paper (although Google Docs does this better).

Google Docs

Google Docs is a public place where anyone with an account can upload documents to the web for storage and sharing purposes. A document is loosely defined as any file, including, for example, spreadsheets, images, PowerPoint presentations, and Word documents. Documents can be accessed anywhere a person has internet access, even on a phone. At the very least, it is a place where you should periodically post your proposal or STEM research paper for safe storage during the writing process. Google Docs, like wikis, allows you to invite other people to view or edit the uploaded document. This is a great way to work collaboratively with group members on the same document without worrying if the "version" of the file is the most current one.

Sending documents as attachments via e-mail may be more private, but it is less efficient. Keeping Google Docs organized is easy because files can be put into folders, much as you do on your own computer, and whole Google folders can be shared. If your group decides to make a wiki, you could even organize one of the wiki pages to link to the Google Docs that the group is currently working on. Although Google Docs is the share location that I will refer to throughout this book, you may have access to alternatives, such as a network drive, or a classroom space within a school portal. Websites such as Buzzword, Zoho, Zimbra, and Microsoft Office Live provide similar services.

Social Bookmarking

Social bookmarking—an online bookmarking system—will save you time as you begin researching your topic and developing the research design. If working individually, any bookmarking system (if organized into appropriate folders) is sufficient. However, if you are working with others on this research project, consider a social bookmarking site like Diigo (*www.diigo.com*) or Delicious (*www.delicious.com)*. These sites allow you to organize your bookmarks as well as leave comments on web pages, highlight text, and share those bookmarks and edits with the members of your group.

References

ACT. 2009. Focusing on the essentials for college and career readiness: Policy implications of the 2009 ACT National Curriculum Survey results. Retrieved May 16, 2011, from *www.act.org/research/curricsurvey.html*

Ayers, J. M., and K. M. Ayers. 2007. Teaching the scientific method: It's all in the perspective. *American Biology Teacher* 69 (1): 17–21.

Bereiter, C., and M. Scardamalia. 2009. Teaching how science really works. *Education Canada* 49 (1): 14–17.

Drake, K. N., and D. Long. 2009. Rebecca's in the dark: A comparative study of problem-based learning and direct instruction/experiential learning in two 4th-grade classrooms. *Journal of Elementary Science Education* 21 (1): 1–16.

Leonard, W. H., and P. M. Chandler. 2003. Where is the inquiry in biology textbooks? *American Biology Teacher* 65 (7): 485–487.

Marcus, J. M., T. M. Hughes, D. M. McElroy, and R. E. Wyatt. 2010. Engaging first-year undergraduates in hands-on research experiences: The Upper Green River Barcode of Life project. *Journal of College Science Teaching* 39 (3): 39–45.

Tang, X., J. E. Coffey, A. Elby, and D. M. Levin. 2010. The scientific method and scientific inquiry: Tensions in teaching and learning. *Science Education* 94 (1): 29–48.

Taraban, R., C. Box, R. Myers, R. Pollard, and C. Bowen. 2006. Effects of active-learning experiences on achievement, attitudes, and behaviors in high school biology. *Journal of Research in Science Teaching* 44 (7): 960–979.

Tarhan, L., H. Ayar-Kayali, R. O. Urek, and B. Acar. 2008. Problem-based learning in 9th grade chemistry class: Intermolecular forces. *Research Science Education* 38: 258–300.

Wong, K. K., and J. R. Day. 2009. A comparative study of problem-based and lecture-based learning in junior secondary school science. *Research in Science Education* 39 (5): 625–642.

2

Research Design

Introduction

In Chapter 1, you worked on focusing your preliminary research ideas. In this chapter, you will learn how experiments are structured. This structure or experimental setup is called the *research design*. The research design of an experiment determines both whether the experiment is likely to succeed and the reliability of its results.

Learning Objectives

The main objective of this chapter is to have you write a first draft of your experimental research design. By the end of the chapter, you should be able to

1. list the main components of an experimental design,
2. describe the purpose of having a hypothesis in a STEM-based research project,
3. explain the importance of doing background research on independent and dependent variables,
4. compare and contrast the individual entities or trials within the experimental groups,
5. describe how constants are different from the control,
6. explain why it is important to consider possible extraneous variables when you are designing a STEM research project,
7. distinguish between quantitative data and qualitative data, and
8. describe how recording only inferences may interfere with data collection.

Key Terms

Constants: The factors within an experiment that are kept the same for all groups or trials in an attempt to reduce the influence of extraneous variables.

Control group: The group in an experiment that receives the exact treatment as the experimental groups *except* it does not receive any change of the independent variable. It is the group to which the experimental groups are compared.

Dependent variable (DV): The variable in an experiment that changes *in response to* the independent variable and, therefore, is also referred to as the *responding variable.*

Experimental groups: The groups or trials in an experiment that receive all the same conditions *except* varying amounts or qualities of the independent variable.

Extraneous variable: An "undesirable" variable in addition to the independent variable that may influence the results of an experiment, introducing error if it is not, as much as possible, controlled or significantly decreased in the research design.

Focal sampling: A behavioral recording technique where a *narrative* (i.e., what is called an *essay* in English class) is written on every behavior of one individual or group for a set length of time.

Hypothesis: A tentative (i.e., not final and definite) and testable proposed explanation for an observable phenomenon.

Independent variable (IV): The variable in an experiment that is purposely changed or manipulated, either in quantity or quality, by the researcher; also referred to as the *manipulated variable.*

Inference: A conclusion, based on facts, that a person perceives to be true.

Population: The complete collection of every item that has the same characteristics of the individuals in the sample group.

Qualitative data: Data that describe characteristics or qualities, such as color, odor, or texture, or data that describe category frequency or ratings, such as stem sturdiness (e.g., "sturdy," "somewhat sturdy," "limp").

Quantitative data: Data that use numbers with a unit of measurement, such as the length of an insect in millimeters (millimeter is the unit of measurement) or the weight of a projectile in kilograms (kilograms is the unit of measurement).

Sample: A subcollection of data that represent a larger population.

Scan sampling: A behavioral recording technique where the activity of the individual or group is recorded only at preselected time intervals.

Sequence sampling: A behavioral recording technique where behaviors that occur within a sequence are recorded in the order in which they occur.

Trial: The replication of experimental and control groups; used to decrease the influence of variations associated with the independent variable, researcher measurement error, and difference between entities studied.

Components of a STEM Experimental Research Design

An experimental research design includes a hypothesis, variables, experimental and control groups, and constants. Each of these elements is briefly discussed below.

Hypothesis

Once you have determined the question you would like to answer, and after you have begun background research, you are ready to modify your question into a testable statement. You do this by writing a *hypothesis*, which is a tentative, yet testable, proposed explanation for an observable phenomenon or event. The purpose of the hypothesis is to formulate what you want to test and defines the limit of your experiment. It is considered tentative because it states a connection that you believe exists and want to test. However, one research experiment will not ultimately "prove" or "disprove" the connection you are suggesting. The purpose of a hypothesis is to *connect the manipulated changes made by the independent variable with the effects on the measurements of the dependent variable.*

Writing hypotheses to be tested through experiments and observations is central to doing research (Gordon 2007). The question you developed in Chapter 1 will help you stay focused as you do your background research. Now, by changing the question into a hypothesis statement, you accomplish several critical research design issues. In writing a hypothesis, you will

1. determine a specific variable to be tested,
2. determine how changes within the experiment will be measured or recorded, and
3. predict an outcome of what you think the results of the experiment will be.

For instance, in the following planaria example, the question only asks "how" reproduction is affected by temperature and is not written in such a way that it could be answered in a single experiment. How the reproduction "effect" would be measured is not clear. Planaria reproduction could be measured many different ways, such as the number of offspring that come from one individual or the mortality rate of offspring. (The independent variable is underlined once and the dependent variable is underlined twice.)

Question: *What effect does temperature have on planaria reproduction?*

> **Hypothesis:** *If the speed of planaria reproduction is related to temperature, then planaria in lower temperatures will reproduce more slowly than planaria in higher temperatures.*

The hypothesis, on the other hand, identifies not only the specific variable to be tested (temperature) but also what will be measured (speed of planaria reproduction). The inclusion of a prediction—that lower temperatures will lower reproduction rates—makes it clear that the experiment is designed to either support or reject that prediction. Hypotheses like this one are testable because (a) one variable is tested, (b) it is clear how the changes will be measured, and (c) it includes a prediction that will be either supported or rejected by conducting the experiment.

You should write your hypothesis after you do your preliminary research but before you begin your experiment. More details about how to write a hypothesis are provided in Chapter 4, "Writing Hypotheses."

Variables

The *independent variable* (IV) is the variable that is purposely changed or manipulated. Information about the independent variable is known before the experiment begins. Independent variables are also known as *manipulated variables* because you change either the quantity or quality of this variable in the experimental groups. Therefore, the independent variable will determine the organization of levels for the experimental groups. Although more complex experiments can have more than one independent variable, research projects that are to be completed over a series of weeks or months should only have one variable that can easily be tested and measured.

The *dependent variable* (DV) is the variable that changes in response to the independent variable and, therefore, is also referred to as the *responding variable*. Essentially, this is the "effect" and the data that you record during the experiment. It is best to quantify measurements as much as possible, but accurate descriptive data throughout the experiment are helpful as well.

Every research question has several ways in which changes could be measured. Background research should help you determine which dependent variables are most likely to show change in the time you have to conduct the experiment. Therefore, it is important to base the choice of your dependent variable on what you have learned in your background research. Plan your experiment so it focuses on a few related dependent variables. For example, for the research question "How effective are plant-based insect repellents?" there are several different options of dependent variables that a researcher could choose.

Research Question: "How effective are plant-based insect repellents?"	
Independent Variable	**Possible Dependent Variables**
Different brands of plant-based repellents (ideally with differing levels of the active ingredient)	• Total number of insect bites • Size of insect bites • Color and/or itchiness of insect bites • Length of time

Experimental Groups

Experimental groups are the treatment groups or trials that receive all of the same conditions, *except* varying amounts or qualities of the independent variable. Experimental groups are sometimes called *treatment groups* because they receive the change of the independent variable. An important component of designing strong experiments is replication (i.e., performing an experiment more than once). In some STEM experiments, experimental groups containing several entities can be running at the same time, while other experiments will have multiple trials, or runs, that are conducted periodically over time.

The word *trials* refers to the number of treatment replications that you perform on experimental and control groups. Having multiple entities in each experimental group or running multiple trials is important because it decreases the influence of variations associated with the independent variable, researcher measurement error, and difference between the entities studied. For example, in a biology experiment with seeds and pH, four experimental groups, each with multiple seeds, can be set up at the same time, each with different pH levels, and data can be collected from each of the groups at regular intervals throughout the experiment. But an engineering research project testing the mechanical advantage of differing arm lengths of a catapult would use multiple trials of each arm length, which would require making adjustments to the catapult in between experimental groups.

By doing thorough background research, you should be able to determine both how many experimental groups to have and the appropriate levels of the independent variable for each of the groups. The organization of the experimental groups is critically important for a strong research design. Having experimental groups that are not varied enough in quantity or quality may not show any change in the dependent variable and, therefore, will not help you determine any connection between your independent variable and dependent variable. Let's look at an example. The following hypothesis is testing to determine a relationship between levels of vitamin C and when a fruit is picked.

If the concentration of vitamin C in oranges is related to the length of time it has been removed from the tree, then oranges freshly picked will have higher levels of the vitamin.

The *experimental groups* for this experiment should be *varying times after the fruit is picked.* It is important that these groups be selected carefully to show an adequate spread of results. If the vitamin C levels are measured in oranges at intervals of 6 hours, 12 hours, and 24 hours, the levels of vitamin might not differ enough to notice. Similarly, experimental groups divided into extreme high and low quantities will not show the detail needed to analyze the effects. If experimental groups in the orange/vitamin C experiment are measured at 1 day, 4 weeks, 8 weeks, and 16 weeks, the levels of vitamin C might be drastically different, but, without multiple gradients of the independent variable, there is no subtle data to determine critical levels or provide insight as to why those changes might have occurred. Therefore, it is important that you use background research to study the variables so that your groups can be set up appropriately.

It is also possible that experimental groups cannot be predetermined. Sometimes, it is only after the data are collected that data can be grouped for analysis. For the river otter experiment shown in Figure 2.1, the data could be categorized into groups based on the range of temperatures that were actually observed on data collection days. The independent variable of this experiment is the change in water temperature and the dependent variable is the frequency of river-otter behaviors that the researcher categorizes as active or nonactive when making observations.

Figure 2.1

Sample Behavioral Ecological Design Table

<table>
<tr><td colspan="5">Hypothesis Draft
Behavior of a river otter in different water temperatures</td></tr>
<tr><td>Independent Variable
Water and air temperature</td><td colspan="4">Background Questions
What is the normal river otter behavior?
How should I record and quantify behavior in my lab notebook?
How quickly does water temperature change in the fall? (Will it be significant enough to study?)
How do otters prepare for the winter months? Behaviorally and physically?</td></tr>
<tr><td>Dependent Variable
Quantitative
None

Qualitative
Descriptions of behaviors
Tallies of specific behaviors (categorical data)</td><td colspan="4">Constants
Make observations at the same time of day
Same otter observed in the same location throughout the experiment

Note: Experimental and control groups can't be predetermined! I will categorize after data are collected, choosing temperature category ranges that match the observation data.</td></tr>
<tr><td>Experimental Groups and Control Group</td><td>Control Group
Average expected temperature for the season</td><td>Exp. Group #1</td><td>Exp. Group #2</td><td>Exp. Group #3
Coolest water temperature</td></tr>
</table>

Control Group

The *control group* is the *one* group to which all other groups will be compared. The control group receives the exact treatment as the experimental groups *except* it does not receive the change of the independent variable. In the orange/vitamin C experiment, the control group would be the level of vitamin C while still attached to the tree (or shortly thereafter), but in all other ways, it is treated and cared for in the same manner as the experimental groups. This way you can determine whether or not there are hidden variables that may be changing without you knowing it.

A control can also be a known measurement or level of the independent variable. In the river otter experiment, the average expected temperature could be designated as the control group.

Sometimes a control can only be designated after data are collected. Also, for some experiments, there is no control group and the comparison among the experimental groups is enough.

Notice there is no control group for the geology research design shown in Figure 2.2. This is acceptable because the data collected at each depth will be compared to one another because the researcher is looking for a pattern in an event that occurred many years ago. This geology research design also highlights how, because the data are located in the environment, there are fewer constants than there would be if completed in a controlled setting.

In the chemistry design shown in Figure 2.3, it is important to note that several trials of this experiment should be performed, and additional experimental group rows could be added in the table to indicate this. Comparing this data to another brand of cosmetics would be a way to expand this experiment.

Both the experimental and control groups are considered a smaller sample of the larger population. Statistically, a *sample* is a subcollection that represents the entire population. The sample is the group from which you actually collect data. The *population* represents a complete collection of every item that has the same characteristics as the individuals in the sample group. For example, in an experiment that has three experimental groups and a control group, these four groups make up a representative sample of the entire population. Understanding that these groups are samples that represent a population is important when you begin to statistically analyze your data after your experiment.

Samples are commonly used in research studies to make claims regarding the entire population. The assumption is that as long as the sample represents the population—that is, that the characteristics of those entities within the sample match those in the population—these types of inferences (claims) can be made. The larger the sample, the more likely this assumption is correct. In the STEM studies we are conducting, rarely if ever, can data be collected from an entire population; therefore data from samples must be studied instead.

Figure 2.2

Sample Geology Research Design Table

<table>
<tr><td colspan="5">Hypothesis Draft
The number and type of fossils will differ at varying depths.</td></tr>
<tr><td>Independent Variable

Soil sample from different depths (meters)</td><td colspan="4">Background Questions
What methods for collecting soil from a cliff will do the least amount of damage? And be safest for me?
How will I identify fossils?
What categories for "type" will I use?
How do I best organize my lab notebook for this type of research?
How will I count partial fossils?</td></tr>
<tr><td>Dependent Variable
Quantitative
Number of fossils (# per kg)

Qualitative
Type of fossils</td><td colspan="4">Constants
Soil samples removed from clliff on the same day
Soil samples spread out and allowed to dry before weighing
1 kilogram from each depth</td></tr>
<tr><td>Experimental Groups and Control Group</td><td>Exp. Group #1
Soil sample from top surface of a cliff</td><td>Exp. Group #2
Soil sample at 5 meters</td><td>Exp. Group #3
Soil sample at 10 meters</td><td>Exp. Group #4
Soil sample at 15 meters</td></tr>
</table>

Figure 2.3

Sample Chemistry Research Design Table

<table>
<tr><td colspan="4">Hypothesis Draft
Comparing color dyes found in cosmetics</td></tr>
<tr><td>Independent Variable
Cosmetics that contain straight dyes</td><td colspan="3">Background Questions
In what cosmetics are dyes found? Which will be easiest to test?
What are the different types of dyes?
What testing has been done on dyes? Are some dangerous?
How are cosmetics tested?
What makes cosmetic dyes stay where they are applied?
Can I use chromatography to distinguish the different dyes?
How do I do that? What supplies will I need?
Are dyes required to be listed in the ingredients?
What makes a cosmetic product darker? Different darker dyes or many dyes used together?</td></tr>
<tr><td>Dependent Variable
Quantitative
# of dyes per product
Qualitative
Description (and photographs) of chromatograms</td><td colspan="3">Constants
Chromatograms are all made from filter paper used from the same package.
Same method of obtaining samples is used for all groups.
Same product and brand is used, but different shades and multiple trials.
Note: Experimental groups will be various shades from lightest to darkest.</td></tr>
<tr><td>Experimental Groups and Control Group</td><td>Exp. Group #1
Lightest color product</td><td>Exp. Group #2
Darker than control. Lighter than group 2</td><td>Exp. Group #3
Darkest color product</td></tr>
</table>

Constants

Constants are the factors within an experiment that are kept the same for all groups or trials in an attempt to reduce the influence of additional variables. Once you have chosen the independent variable, you must design an experiment to take all of the other potential independent variables into account and make them constant. Otherwise, you will not be able to support a clear relationship between the two variables for which you have data.

How you decide to perform the experiment, meaning the step-by-step procedure, is crucial and can greatly influence the integrity of your experiment. Your treatment of each of the groups must be the same in every way. When analyzing the data after the experiment, you will have to critique your methods to see if something you may have done, or failed to do, influenced the results. This is another reason why background research before starting the experiment is so important.

You need to consider what it means to provide a constant environment for all the groups. For example, in a plant experiment where different intensities of light are used, it is likely that the soils will dry out at different rates. Does keeping the water a constant mean that each plant gets watered the exact amount, on the same days of the week? Or does keeping the water a constant mean that each plant gets enough water so that its soil is moist 1 cm below the surface? Although there is not always a "right" answer to these types of questions, you need to do background research to determine which methods would introduce the least amount of error.

In the reproduction/temperature experiment on planaria (pp. 17–18), the constants might include the methods used to observe and handle the planaria, the length of time each group receives light, and how often planaria are fed and environments cleaned. The list of conditions to keep constant within your experiment can be extensive. It is important to learn as much as possible about the entity being studied AND about the independent variable. You want to be as informed as possible about any additional factors that may influence the results.

Be careful that by controlling for one extraneous variable you are not introducing another one. An *extraneous variable* is a variable in addition to the independent variable that may influence the results of an experiment. Extraneous variables can introduce errors if they are not controlled or significantly decreased. For example, if planaria specimens are placed in different rooms to keep the varying temperatures from interfering with the experimental and control groups, additional variables have now been introduced. The different rooms might have varying amounts of light or might be used more or less frequently by people. You will not be able to control everything, but you will have to make decisions on what is least likely to influence the results. Be ready to address any limitations of the experiment. Explaining the efforts that went into reducing the effects of extraneous variables is important. Figure 2.4 shows a sample of what a biological experimental design might look like when put into an experimental design table.

Difference Between Quantitative Data and Qualitative Data

Quantitative data are data that use numbers with a unit of measurement—for example, the length of an insect in millimeters or the weight of a projectile in kilograms. *Qualitative data* are data that describe characteristics or qualities, such as color, odor, or texture, or data that describe category frequency or ratings, such as stem sturdiness (e.g., "sturdy," "somewhat sturdy," "limp"). Therefore, both describe the same situation but in different ways. While quantitative measurements are of upmost importance in all STEM-based research, qualitative descriptions of data are appropriate to supplement and give a different view of the same data.

Quantitative = data that can be expressed in numbers (quantified)

Qualitative = descriptive data or data that has been put into categories (i.e., categorized data)

Quantitative Data Uses

Quantitative data are the primary data collected for most STEM research. The purpose in collecting quantitative data is to enable you to categorize, organize, and classify your observations in such a way that the experimental groups can be compared mathematically to one another and to the control group. In other words, the quantitative data collected throughout the experiment (hourly/daily/weekly) can later be calculated into changes over the course of the experiment to determine if the difference is statistically significant. End of the experiment mathematical calculations may include means, modes, medians, total change, rate of change, or speed of change. These numbers are used to determine whether the differences are statistically significant. See Chapters 7–9 for a lot more information about mathematical analyses.

As the researcher, you will first consider quantitative measurements by measuring the effects of the dependent variable. You must consider using

Figure 2.4

Sample Biology Research Design Table

<table>
<tr><td colspan="5">Hypothesis Draft
If the amount of solid surface on top of the soil is related to the strength of the seedling, then seedlings will break through thinner surfaces more consistently and with less damage to the seedling.</td></tr>
<tr><td>Independent Variable
Varying depth of solid surfaces for seedlings to grow through</td><td colspan="4">Background Questions
What species of seeds would best be used?
What type of seed has a fast germination rate and is easy to grow in controlled conditions?
What are the best solid surfaces to use? (Plaster of paris, concrete mix, spackling paste?) What other variables might be introduced by using these materials? How can I reduce those?
What are the best ways to measure "strength" of seedlings? (Crack of surfaces, speed at which they get through the surface?)</td></tr>
<tr><td>Dependent Variable
Quantitative
# of days it takes to break through surface
width/length of the crack
Thickness of seedling stem
Qualitative
Condition of the seedling during and after breaking through surfaces
Conditions of roots and seedling</td><td colspan="4">Constants
Seedlings all have the same lighting, watering, and feeding schedule (plants are rotated weekly).
Data collection is done at the same time every day.
Temperature of the room remains the same for all seedlings.
Seeds of the same kind came from the same package.
Seeds are all planted in the same type and size container (clear plastic cup).
All seeds have the same quality and amount of soil underneath the solid surface.</td></tr>
<tr><td>Experimental Groups and Control Group</td><td>Control Group
No solid surface (just soil)</td><td>Exp. Group #1
.5 cm depth solid surface</td><td>Exp. Group #2
1 cm depth solid surface</td><td>Exp. Group #3
1.5 cm depth solid surface</td></tr>
</table>

mathematical measurements such as area, angle, conductivity, density, electrical current, force, heat, humidity, length, light intensity, mass, pH, pressure, salinity, temperature, time, velocity, volume, or others. Your teacher will most likely require you to use only metric units or the International System of Units (SI), so you will use *centimeters* instead of *inches* and *liters* instead of *gallons.* The quantitative data you choose to record should be based on your background research.

Be sure to have reasons that support the relationship between the independent and dependent variables. For example, in an experiment that seeks to determine whether powdered drinks contain different food dye concentrations, it would not make sense to measure pH because pH is not the factor being studied in the relationship between the variables.

Quantitative data are used primarily to measure your "effects." There are other ways, however, in which quantitative measurements are a part of your experiment. First, you need to record measureable differences between your experimental groups. For example, if your independent variable is pH, you must record accurate measurements to ensure that the pH levels for each experimental group are appropriately different from one another. Second, you need to record quantitative measurements to ensure that extraneous variables remain constant. For example, temperature is often an added influence in an experiment and so must remain constant. Therefore, you must find ways within the experimental design to keep temperature the same and then plan to monitor and record this measurement periodically throughout the experiment.

The type of data and how you collect it will depend on what type of STEM research project you plan to do. In mathematics, physics, and population and human genetics research, the data may already exist. You may even be able to find reliable resources of data online. Then, it is a matter of obtaining the data and organizing it so that an analysis correlating it to the dependent variable can be made.

Qualitative Data Uses

Qualitative descriptions help you record changes within your experiment that may not necessarily be measureable. When collecting these observations, you describe how something looks, smells, feels, sounds, or tastes (when appropriate) or categorize it into a specific category. However, just because you may not be using numbers, don't lose your objectivity. Your observations should be scientific in nature and not make judgments or inferences. An *inference* is a conclusion, based on facts, that is perceived to be true by the researcher. Be careful, however, when you make an inference. The statement

"The solution looks normal" is an inference, but this conclusion obviously is based on observations that are not recorded. Although you may know what you mean, inferences written without factual descriptions will not help you compare results at the end of the experiment. Statements that include inferences are best saved for after data are collected. Instead, the actual observations, which lead to the inferences, should be recorded. Remain scientific and use detailed and descriptive language.

If you have trouble determining how to describe qualitative data, ask yourself, "What is 'normal' about this?" Make a long list of adjectives to describe the qualitative aspects of your dependent variable. For example, if you are studying viscosity of a fluid, list words that will help you describe varying thicknesses of the solutions—for example, *stringy, thready, dense, clumps,* or *runny*. If you photograph the entities throughout the experiment, you'll be able to compare qualitative differences. You may notice something in photographs that you didn't notice on a day-to-day basis. These observations will help supplement the quantitative data that you collect.

In addition to narrative descriptions, qualitative data can also be in the form of category frequency or ratings, both of which use numbers. Counting frequencies allows you to keep track of changes that are not normally quantified. For example, to record color change, you could use paint swatches, with each gradient of color assigned consecutive numbers—perhaps low numbers for lighter shades and higher numbers for darker shades. In a catapult-testing experiment, after research and/or pretrials, you might determine that there are three basic arch shapes in which the projectile might fall. After each trial, you could measure distance (quantitative) but also determine which of the three arch categories a catapult belongs to (qualitative).

If you choose to do behavioral research, you might collect data on location, like at a zoo, for animal behavior or at a coffee shop for human behavior. Recording behavior is a good time to use qualitative data. Behavioral research can be recorded several ways; the most common are focal sampling, scan sampling, and sequence sampling (Morgan 2009).

- In *focal sampling*, you choose one individual or group of individuals and record your observations for a set length of time. You watch and record everything you observe, writing in a narrative form.
- In *scan sampling*, you record the activity of an individual or group at preselected time intervals. Scan sampling should give you a sample representation of the behaviors taking place, and if you predetermine categories, it will also allow you to tally behaviors that can be used in data analysis. For example, if using scan sampling in the river otter experiment (Figure 2.1), you might observe the river

otter in two-minute segments for several hours. At the moment each two minutes has passed, you would record what the otter is doing. Otter behavioral categories to be tallied might include walking, swimming underwater, floating on back, diving, grooming, foraging, or playing. Scan sampling helps keep an accurate record of observed behaviors as well as a record of changes over time if multiple observations are made.

- In *sequence sampling*, you record behaviors that occur within a sequence, in the order in which they occur. The rubric in Table 2.1 is an example of sequence sampling. The rubric was designed for a horse-training experiment in which the researcher wanted to keep track of a horse's progress as it learned a new skill. The behavior (taking a first step) was broken down into smaller pieces and then used during each training session to record the progress of the horse as it learned the new behavior.

Table 2.1

Sample Rubric for Observation of Horse Behavior (From Lifting the Hoof to Taking First Step)

1	2	3	4	5
Slightly bends knee for less than a second and puts back on ground	Bends knee but leaves toe of hoof on ground for about a second and then puts weight back on ground	Lifts hoof off ground but puts it back down less than a second	Lifts hoof off ground for a second and then puts weight back on ground	Lifts hoof off ground for more than a second

Table 2.2 shows sample quantitative and descriptive data for various types of research projects. The table may help you tell the difference between quantitative data and descriptive data that you collect during your experiment.

Table 2.2

Sample Quantitative and Qualitative (Descriptive) Data for STEM Research Projects

STEM Field	Entity Studied	Quantitative Data	Qualitative (or Descriptive) Data
Anatomy and physiology	Elbow joint range of motion (ROM)	110°	Patient winced at 95° but was able to go to 110°.
Biology	Earthworm growth	62 segments above the clitellum, 170 below	Worm pink at the posterior end and brown everywhere else.
Chemistry	Precipitation reaction	2.1 g	Bright yellow precipitate = 4 (scale 1–5)
Geology	Soil porosity	360 ml	Color of the soil did not change with the addition of water, but a bitter odor was noticeable.
Mathematics	Travel time	40 min.	The roads were wet because it was drizzling at the time of data collection.
Physics/ engineering	Tensile stress and strain	87 g 6.4 cm	Cord made loud cracking sounds before it snapped.

Chapter Questions

1. What are the main components of an experimental design?
2. What is the purpose of having a hypothesis in a STEM-based research project?
3. When doing background research on independent and dependent variables, what sort of information will help you write a good research design?
4. How do the individual entities or trials within the experimental groups differ? How are they the same?
5. How are the constants different from the control?
6. How should the consideration of extraneous variables affect the design of a STEM research project?
7. How do quantitative data differ from qualitative data?
8. Why might recording inferences (instead of facts) interfere with data collection?

Chapter Applications

Now it's your turn. Look back at your Student Handout #1, Focusing Preliminary Research Ideas, on page 14. Use it to complete the Student Handout #2, the Research Design Table, on the following page. Refer to the example design tables provided in this chapter. Carefully consider the elements of your experiment. Think about the variables that can best be observed and measured, taking into consideration the equipment, resources, and lab skills you have at your disposal. Consider advice and suggestions from your teacher and your classmates. Completing this table in writing will help you determine the strengths and weaknesses of your research design. It will tell you what you still need to learn more about. Don't be surprised if you complete several drafts of the table, maybe on completely different topics.

If you are working with a group or with a partner on this project, your teacher may prefer that you brainstorm together regarding the research ideas and variables and then complete the remaining parts of Student Handout #2 individually. In that case, group members can discuss the differences between the different proposed research designs and then combine the best of each version to make a single group draft. At that point, consider typing up the group draft and posting it to a Google Doc that you can share with all members of your group and with your teacher (for more information on Google Docs, see p. xxviii). In that way, each group member can make edits to the document, and the teacher can check on the group's progress.

The next chapter will help you develop research questions to help focus your background research. Continue doing background research on your topic. Though it may seem contradictory, the more background information you have, the better you will be able to modify your research design.

References

Cothron, J. H., R. N. Giese, and R.J. Rezba. 2006. *Science experiments and projects for students: Student version of students and research.* Dubuque, IA: Kendall/Hunt.

Filson, R. 2001. In search of ... real science. Retrieved March 4, 2011, from Access Excellence: *www.accessexcellence.org/LC/TL/filson.*

Gordon, J. C. 2007. *Planning research: A concise guide for the environmental and natural resource sciences.* New Haven, CT: Yale University Press.

Morgan, K. 2009. Notes on behavioral recording techniques. Retrieved March 15, 2011, from Wheaton College website: *www3.wheatonma.edu/kmorgan/Animal_Behavior_Class/recordingmethods.html.*

Student Handout #2

Research Design Table

Name ______________________________ Class __________ Date ____________

Directions: Complete the following table with your research project idea.

<table>
<tr><td colspan="5">Hypothesis Draft</td></tr>
<tr><td>Independent Variable</td><td colspan="4">Background Questions</td></tr>
<tr><td>Dependent Variable
Quantitative

Qualitative</td><td colspan="4">Constants</td></tr>
<tr><td>Experimental Groups and Control Group</td><td>Control Group</td><td>Exp. Group #1</td><td>Exp. Group #2</td><td>Exp. Group #3</td></tr>
</table>

INDEX

Page numbers in *italics* refer to figures, tables, student handouts, forms, or boxed sidebars. Page numbers in **bold** refer to Key Term definitions.