11

Writing the STEM Research Paper

Introduction

You have completed your STEM research experiment and performed statistical analysis. It is now time to organize your information so that you can write the paper or design a poster. To begin, you may want to create an outline or a graphic organizer (e.g., a chart or concept map) to help you determine what you will put in each section. The STEM research paper or poster you are going to write will be organized into five sections: Introduction, Materials and Methods, Results, Analysis and Conclusions, and Works Cited. You might also have one or more appendixes. Before you begin writing, please review the plagiarism precautions found in Chapter 3 (pp. 47–48).

Learning Objective

By the end of the chapter, you will be able to list and describe the five sections of the STEM Research Paper.

Key Terms

Abstract: A single paragraph that summarizes a research project. Its purpose is to help readers quickly and easily decide whether or not they want to read the paper. Abstracts include what was studied, how it was studied, the results, and a brief analysis of those results.

Analysis and Conclusions: The section of a scientific paper that interprets the data that were reported in the Results section.

Introduction: The section of a scientific paper that states the problem or project topic and tells why the problem or topic is being studied in an experiment. The introduction should include documented background research on the entity being studied, the independent and dependent variables of the experiments, and the various methods that will be used.

Limitations: The part of the Analysis and Conclusions section that discusses anything about the experiment that may weaken the confidence level of the results. Limitations may include extraneous variables not kept constant, poor sampling, or instrument errors.

Materials and Methods: The portion of a scientific paper that tells how the study was conducted, what equipment and techniques were used, and what procedures were followed. The description of the procedures should be detailed enough so that so that someone else could replicate the experiment exactly.

Results: The section of a scientific paper that reports on the experimental findings of the research study, including the statistical analysis of the findings. It should include both graphics and a written account.

If you performed the experiment as a group, your teacher may still expect each group member to write an individual STEM research paper. If, on the other hand, your teacher expects to receive a single paper that represents the work of the group, that paper must flow as if it were written by a single person (even if parts of it were written by different group members). In particular, take care to ensure that the wording between sections (the transitions) is smooth and that the paper reads as one cohesive piece. Don't just copy and paste each group member's portion into the same word-processing file the night before the paper is due. Instead, each group member should write his or her pieces in a single document that everyone edits, such as a Google Doc.

Some groups find that writing the entire paper together in Google Docs is more constructive than dividing the writing among members. It is up to the teacher or group to decide. In either case, *before you begin the paper,* write up a contract agreed on by all group members that clearly establishes everyone's roles.

In any case, remember to back up your electronic files. Every couple of days save the file(s) in at least two places, perhaps on a computer hard drive, disk, or flash/thumb drive. You can also back up files by uploading a copy online—using services that will store files online for free (e.g., Dropbox at *www.dropbox.com*) or uploading a new copy each week to Google Docs. Another simple backup procedure is to send e-mail attachments of the file to yourself or a friend. Your friend could keep the file in his or her inbox or save it to the hard drive. You will be spending too much time on this piece of work to rewrite it. Back up your files regularly.

Parts of the STEM Research Paper

Your STEM research paper will have five (or more) sections: Introduction, Materials and Methods, Results, Analysis and Conclusions, and Works Cited and maybe an abstract and appendixes. When typing your paper, you should center these headings on the page, without any special bolding, italics, or underlining. Don't use all capital letters; copy the style that is used in this paragraph.

Introduction

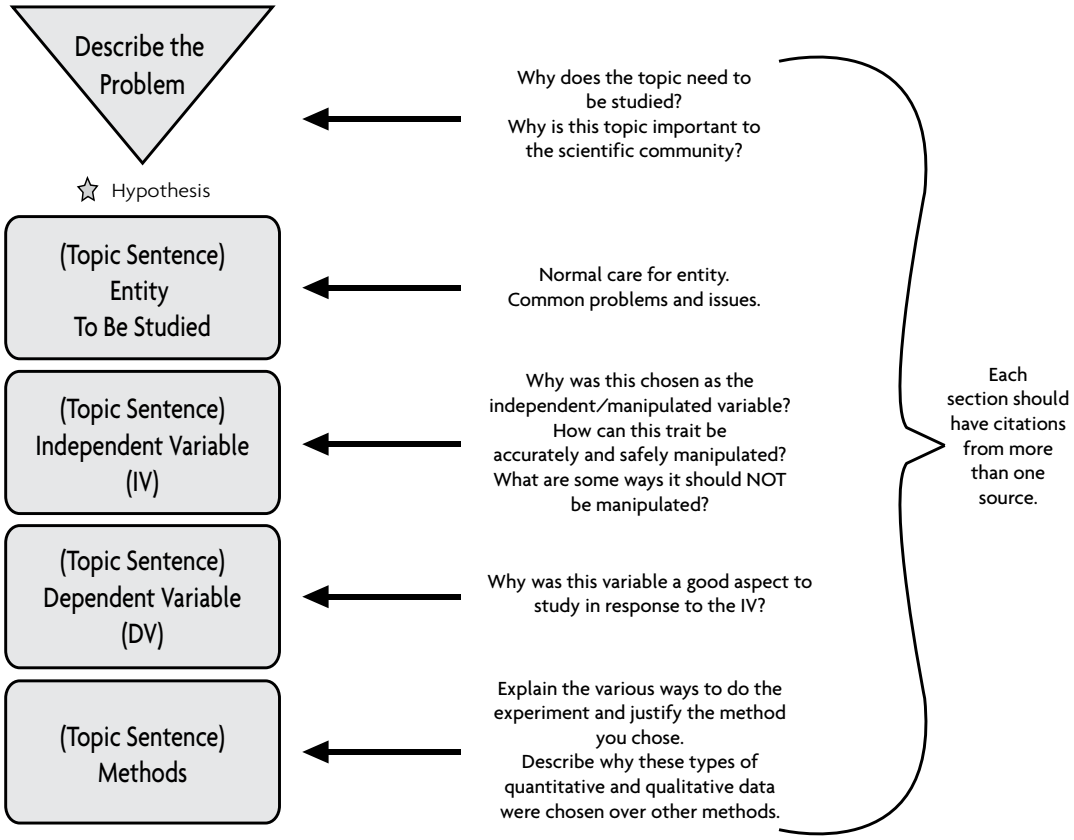
As noted in Chapter 5, when you were working on writing your proposal, the purpose of the Introduction is to state a problem or project topic and why you are studying it. You should explain how the experiment you designed addresses the larger problem. An Introduction is more than just a summary of your background research; it should address the questions you researched while developing your research design. In other words, the Introduction should weave together your background research on the independent and dependent variables with your data collection methods. The Introduction should show the path you took to address the problem. As a whole, it should move from general to more specific.

Write the Introduction as if it were an essay that could stand on its own. Figure 11.1 (p. 160) will help you organize this part of the paper. The inverted triangle shown in Figure 11.1 represents the first paragraph(s) of the Introduction. The opening sentences of these first paragraphs should be written in broad terms, explaining the context of the problem that your research study will address as well as the importance of the study to the scientific community. The last sentence of paragraph 1 of the Introduction should *be a version of the hypothesis*. For example, that sentence might be something like, "Therefore, this research study was conducted to look for a relationship between ____ and ____."

Once you have written the first paragraph(s) of the Introduction (i.e., the "Describe the Problem" part), you organize the body of Introduction. Each rectangle in Figure 11.1 represents a part of the Introduction. The key is to begin each paragraph with a topic sentence that explains what that paragraph will talk about. As noted in Figure 11.1, write a paragraph(s) on the entity studied. Describe the care needed for the entity and any safety or other common issues that can arise when working with this entity. Also include paragraphs on the independent and dependent variables and, in the context of your hypothesis (which you stated earlier in the last sentence of the first paragraph), explain why these variables were chosen.

Figure 11.1

Paragraph Organization for Introduction of a STEM Research Paper



In addition, cite studies you found during your background research that were similar to your study (put the name of the author of each study in parentheses; make sure that that author also is listed in the Works Cited section). Explain how the other studies differed from what you were trying to accomplish. Finally, explain the method you used, possibly defending why it was used if there are several methods that could have been used.

Refer to the MLA documentation chapter (Chapter 10) as well as to the suggestions provided for scientific writing in the proposal chapter (Chapter 5, especially pp. 73–75). Use your notes, not the original sources, as you write. Be sure to cite more than one source per paragraph. This increases the reader's confidence that your research was thorough—that is, that you verified the information you found in one place with the work of a different researcher. Rely on your teacher's guidelines regarding whether active or passive voice is preferred and whether pronouns are appropriate in the introduction (see p. 74).

Materials and Methods

You will combine three sections from your proposal—Hypothesis, Materials, and Methods (see Chapter 5)—into one section—Materials and Methods—in the final paper. In the Materials and Methods section, you describe how you conducted the study, what equipment and techniques you used, and what procedures you followed. Use your proposal as a starting place for this paper.

If, when you were writing your proposal, your teacher had you write the Methods section in paragraph (narrative) form, you will only need to make some grammatical changes (e.g., perhaps change the future tense to past tense—for example, the statement, "I will heat the solution to 40ºC" would be changed to "I heated the solution to 40ºC.") and update the Methods section to communicate what actually occurred. However, if you wrote a numbered list of experimental procedures for your proposal, you will need to rewrite this section into narrative form.

The hypothesis that your teacher approved in your proposal should be integrated somewhere into this section. You could begin the section by stating what the study was designed to test, then give the exact wording of your hypothesis. (However, you might find the hypothesis fits better at the end of this section.)

A separate materials list is not needed for the final paper. Instead, just make sure that *each item you actually used* is mentioned in the Materials and Methods section.

The Materials and Methods section is also the place to insert photos of the experimental setup and photos of how data were collected. Each photo is considered to be a "figure" in the paper, so give each photo a figure number and title and mention it in your narrative, directing the reader to look at the figure—say, for example, "The pH was measured using a probe, as shown in figure 4. (See the Results section later in this chapter for more information on putting tables and figures into MLA style.)

Although you will not be including the entire Experimental Design Table (from Chapter 2) from your proposal in you final paper, you could modify it into a smaller table to compare your experimental groups with your control group (see Table 11.1). If you choose to do this, be sure to refer to it in your narrative.

Table 11.1

Group Description for Experimental Design

Control Group	Experimental Group #1	Experimental Group #2	Experimental Group #3
No potassium (K)	5 g	10 g	15 g

Results

The purpose of the Results section of the paper is to provide your reader with the experimental findings of your research study, including a statistical analysis. Do not, at this point, attempt to explain what the data mean. In the Results section, you just describe the results without making *any* judgment as to what the results may, or may not, indicate. Therefore, graphical representations of the data paired with text will make up this section. (Refer to Chapters 7, 8, and 9—on statistical analysis—for discussions of how to present the specific types of data you analyzed.)

Organizing the Results Paragraphs

Start this section with an explanation of how you prepared the data for analysis. Tell what mathematical computations and statistics you performed on the raw data to prepare the data for analysis. The purpose of this explanation is to be transparent—sharing how you prepared the data for analysis allows for both a critical review by others and a possible replication and analysis in exactly the same way.

Your laboratory notebook contains many more tables, graphs, and diagrams than you will actually put into your paper. What you write about in the Results section will be based on the graphic images you choose to include in the final paper or poster. Use strong topic sentences to signal to your reader what data you will be presenting. These paragraphs, when organized well, should make clear the trends and patterns in the data. (It is possible that you may have outliers—that is, points in a sample that are widely separated from the main cluster of points—in the data. Do not ignore these. Instead, address them plainly, without giving possible explanations for why they happened.)

When referring to data from specific days of the experiment, do not use the actual dates because they don't give your reader any indication of how that data compares to other data in the experiment. Instead, refer to the *day* of the experiment. For example you would say "on day 17 of the experiment…" not "on February 2…." Calendar dates are in your laboratory notebook for your own reference, but do not use them in the narrative. However, you can provide the beginning and ending dates of the experiment for general reference. For instance, in an experiment relating to weather conditions, knowing the particular date or time of year might be especially important in analyzing or replicating the experiment.

The Results section is written in the past tense. As for which "voice" to use, check with your teacher as to whether active or passive voice is preferred and whether personal pronouns should be used (refer to pp. 73–75). Some readers find the use of the pronoun "I" distracting—for example, "I then took

the raw data for each group and calculated the mean." In the passive voice, that sentence would read, "A mean for each group was calculated." As you can see, a sentence constructed in passive voice reduces the emphasis on who did the calculations.

Preparing Tables and Figures for the Results Section

As explained in Chapter 10 on MLA style documentation, all visuals or graphics that are not classified as tables are called *figures.* Each table and figure must have an assigned number as well as a title that clearly describes what it displays. Tables are numbered consecutively, in the order they appear in the text. The same is true of figures. Tables and figures, however, are numbered independently of each other. For example, on the same page you could have both Table 3 and Figure 3.

Each table and figure number should appear in two places: in the title of the table or figure and in the text that refers to the table or figure. Also, tables and figures must appear in the order that you refer to them in your paper. For example, if Table 1 is a table comparing the control and experimental groups, you must refer to it in the text and it should appear on the page *before* Table 2 appears.

When referring to tables and figures, do not capitalize the *t* or the *f.* (You might have noticed that in this book the *t* in *table* and the *f* in *figure* ARE capitalized. That is because the publisher of this book uses the *Chicago Manual of Style*, which has different rules from the MLA style handbook.). So, in your paper, an in-text reference might read, "The dew point spiked to 89.7 on day 12 of the experiment, but leveled out between days 15–20 (see figure 1)."

When you are referring to tables and figures in the text of your paper, refer to specific aspects within the table or graph, not just to its number. See sidebar for specific examples.

Any table or figure too big to put in the text of the paper, such as a long questionnaire given to study participants, can be put in an appendix that is

How to Refer to Tables and Figures in a Research Paper

Poor Example: There were three mathematical patterns found. See figure 6.
Good Example: In all six sets of sheet music analyzed for this study, all but one showed a pattern between the speed at which the music was to be played and the number of notes. As figure 6 shows, the number of musical notes in measures to be played at *adagio* was consistently half of those to be played at *presto*. However, one musical piece, shown by the dotted line in figure 6, showed no such relationship between speed and number of notes.

Poor Example: All the algae groups grew over the course of the experiment. See figure 3.
Good Example: The algae group with the highest acidity levels grew an average of 3 cm^2 in the first week of the experiment. But as the sharp decline in figure 3 shows, the total surface area decreased, ending with only 2 cm^2 growth at the conclusion of the experiment.

placed after the Works Cited. These tables or figures must be referred to in the paper even though they appear as appendixes. Number them in the order they are referred to in the paper (Appendix 1, Appendix 2, etc.). Appendixes are considered a part of the paper. Also, any written permissions you had to get in order to do vertebrate or human subject research are considered appendixes. Each is given its own number (e.g., Appendix 3) and is referred to in the paper.

Tables and figures are the keys to well-done Results and Analysis and Conclusions sections. When your teacher is evaluating your paper, he or she will use the visuals in the Results section to look for patterns, strange occurrences, and large and/or small changes in the data. He or she will then check to make sure that you have discussed these occurrences in the Analysis and Conclusions section.

Analysis and Conclusions

The purpose of the Analysis and Conclusions section is to explain the data you reported in the Results section. (In some STEM journals, this section is called the Discussion.) It can be the hardest section to write because you must interpret your results and draw conclusions, processes you might not have a lot of experience with. An important component of the Analysis and Conclusions section is that you declare the hypothesis supported or not supported or partially supported (Day and Gastel 2006).

Introductory Paragraph to the Analysis and Conclusions Section

Begin this section by stating whether or not the hypothesis was supported and making general comments as to how strongly it was (or was not) supported. Then list your explanations for this finding that you will be discussing in the rest of this section. You explain the evidence to support these claims in the supporting paragraphs. Ask your teacher if you are to use first person in this section. If you are, the sentence can read, "My hypothesis was not supported because…." However, if your teacher prefers that you stay neutral in your remarks, that sentence might be worded more like, "The hypothesis was not supported because the water level of retention ponds varied more throughout the spring than all the other bodies of water in the study."

Next, list all of your possible explanations: "This may have occurred because a, b, c, d, e, or f." (This sentence, or sentences, acts like a thesis statement in an essay.) Then you address the reason you gave as "a" in its own paragraph. Next you address "b" in the next paragraph, and so on. You might prefer to write all the explanation paragraphs first, decide what order they should be presented in, and then write the thesis statement ("This may have occurred because a, b, c, d, e, or f").

Paragraphs in the Analysis and Conclusions Sections

Each paragraph should address *one* aspect of the explanation of the results. To help the reader through this section, topic sentences should clearly tell him or her what will be discussed in each paragraph.

Because all the data were presented in the Results section, you only need to restate the results that you want to comment on. It is appropriate to refer the reader back to tables and figures in the Results section. When explaining the results, don't use words such as *obviously, clearly,* or *proves.* The words *obviously* and *clearly* are insulting to your reader (who, you should assume, doesn't need to have the obviousness of something pointed out to him or her), and *proves* is too strong a word for a single study.

When appropriate, discuss any groups that had irregular results compared to the rest of the groups. Try to explain why this might have happened. Also, in your explanation of the results, be sure to address questions that were posed by your peers in the peer editing exercise you completed in Chapter 6.

All the trends and patterns you reported in the Results section must be explained. In other words, you must answer the question, "Why did that happen?" Most important, you will need to do all of this—explain your results—by citing past research that is documented according to MLA style. Here, of course, you will have to go back to your background research. All scientific facts MUST be documented, not assumed. For example:

> *During the fall, hydras reproduce sexually (Lentz 13). Even if conditions were right for sexual reproduction and two hydras—such as the two in culture 15—started to reproduce sexually, this would not show up in this experiment because a fertilized hydra egg can take three to six weeks to hatch (Lenhoff 2).*

It is also appropriate to say that your methods might have influenced the results. However, you need to do more than just suggest a possible influence; you must explain *how* the methods may have influenced the results and what could have been done to prevent that influence. For example:

> *Despite my efforts to control the amount and intensity of light exposure during the experiment, I was not as careful about monitoring the light for each of the specimens while collecting data each afternoon. Some specimens were out of their controlled lighting setup for longer periods of time than other specimens. The additional variable of exposure outside the light setup may have influenced the results. This is particularly true for the experimental group that was to be exposed to no light. In future experiments, time to collect data should be equivalent and monitored.*

Other Topics to Be Included in the Analysis and Conclusions

Limitations

After you have discussed all explanations of the results, you need a paragraph on the limitations of the study. *Limitations* are aspects of the research that may weaken the confidence level of the results. For example, maybe there were variables you were not able to keep constant, and therefore, extraneous variables may have influenced the results. Or there were problems that occurred during the study that limit your ability to apply the results to a more general conclusion. Or the number of trials or number of data collection days may not have been sufficient to apply the results beyond this study. Address limitations within the body paragraphs of this section as they apply to specific aspects of the research or you address them in a paragraph of its own at the end of the Analysis and Conclusions section.

The Analysis and Conclusions should connect back to your Introduction. You chose to do this study to address a general question you had. Now you need to connect whether or not your research study provided any answers to that original question. You may also want to discuss the possible applications and extensions of your research study. Describe possible research studies that could be completed in the future. These suggestions might be slight modifications of your own study or extensions that could be completed to answer new questions brought up by your research study.

Apply the results of your experiment globally to the scientific community as a whole. Explain why this study was important. Then discuss new questions that have emerged from your study. Remember, the more you know, the more you know you don't know! By addressing your original question, you probably uncovered more questions that could be turned into future studies.

Last Paragraph

The last paragraph in the Analysis and Conclusions section should summarize your analysis. The topic sentence should declare the degree to which the results show a relationship between the independent and dependent variable or a difference between the groups. The sentence might begin, "Based on this study, [independent variable] does influence [dependent variable]." (If the research results were unclear, or inconsistent, then the topic sentence might be more like, "Because of the limitations of this study, a connection or lack of connection between [independent variable] and [dependent variable] cannot be made.")

Don't use the word *proves* when talking about this relationship. One experiment does not *prove* anything. Instead, use the word *supports*—for example, "This experiment supports the hypothesis that pressure…." The rest

of the paragraph can explain how that final conclusion was made. Another sentence for this final paragraph might be, "Before any strong statement of correlation can be made, additional studies that address the limitations previously mentioned must be conducted." After reading this last paragraph, your reader should know the connections between the variables and the reasons for that correlation or lack of correlation.

Works Cited

See Chapter 10 for a complete discussion of preparing the Works Cited list.

Personal Reflections

In a separate piece of writing (or as a final part of your paper), your teacher may ask you to reflect on the experience of doing your own research and writing the STEM research paper. This is your chance to share how you felt about your experience of being a real scientist. You might use some of the following questions for your personal reflections. The reflections should be real, specific, and honest.

- Why did you do this experiment? What made you curious about this topic?
- Did you find out what you thought you would, or something different?
- How has the question you explored helped you see scientific studies in a new light?
- What about your topic would you have liked to learn more about? Explain.
- Did you have frustrations with the experiment or paper? Explain. How did you overcome them?
- What would you do differently if you were to redo the experiment?
- What advice do you have for students who might be asked to complete their own research studies?
- What experimental topic would you explore if you were to do another research study of this magnitude?
- Why do you think you are required to do this huge research project? What skills did you learn doing this project that will apply to your future?

Abstract (for Oral and Poster Presentations)

An *abstract* is one paragraph that summarizes your entire research project. It is used to help people decide what papers or posters they want to spend time reading. Abstracts include what was studied, how it was studied, the results, and a brief analysis of those results. You will most likely be asked to submit an abstract if you are presenting your results at a research symposium. Your teacher may ask that you submit it with your paper for evaluation. Here are some guidelines for writing an abstract.

Step 1 (one sentence): Describe the project's purpose, using the hypothesis.
Example: The purpose of this research was to determine if increasing the number of hours of light a plant receives also increases leaf width and stem height.

Step 2 (three to five sentences): Describe the methods used.
Example: Three experimental groups and one control group were set up. Each experimental group was exposed to different levels of light—4 hours, 10 hours, and 24 hours. The control group had 12 hours of light. The quantitative measurements—leaf width and stem height—were collected every other day. Data were collected for three weeks.

Step 3 (three to five sentences): Describe the results; be sure to mention the best-performing and least-performing groups and the results of each.
Example: The plants that received 24 hours of light had the most change, with an average of 7 mm of leaf growth and 10 mm of stem growth. The plants that received 4 hours of light had the poorest average growth, with leaf size decreasing by 2 mm and stem growth of 1 mm.

Step 4 (three to five sentences): Conclusion; explain whether or not the hypothesis was supported, and give brief possible explanations for the results.
Example: The hypothesis was not supported because the plants with the least light exposure had the most growth. There may be several explanations for this...

If it makes more sense in terms of your research design, you may want to describe your results and conclusion together in the abstract. For each

experimental group, explain what the results were, followed by your explanation of these results. Make a real effort to write very clear explanations.

Preparing the Paper for Submission

If your teacher gave you a grade sheet or rubric for your rough draft, take careful note of the points made there as you write and revise your paper. You'll find examples of both in the appendix section of this book: "Research Paper Grade Sheet" (Appendix C, pp. 197–200) which is a shortened version of the "Research Paper Grading Rubric" (Appendix D, pp. 201–210). Either of these will help focus you as you begin writing a rough draft.

It is always a good idea to schedule a few days between when you finish writing the rough draft and when the rough draft is actually due. Walking away from your writing and then going back with a fresh perspective will increase your ability to make important edits. It is also advisable to have someone else read your paper, especially if this person has written a STEM research paper like the one you have. Your teacher may have you exchange papers with your classmates and use Student Handout #6 (pp. 171—175).

After reading the feedback from your peer editor, you can decide whether to take or reject the advice; it is up to you. If you don't understand some of the editor's comments, talk to him or her directly or seek a second opinion.

Materials to Accompany the Paper

When it is time to submit your final paper, your teacher may ask you to turn in other items together with the paper. These may include the following:

- Approved proposal
- Laboratory notebook
- Access to social bookmarking group
- Note cards, note packet, or access to your online note organization
- Printed internet sources cited in your paper
- Peer-edited and/or rough draft version of the paper

Chapter Question

List and describe the five components of a STEM research paper.

Chapter Applications

Your STEM research paper will have five sections: Introduction, Materials and Methods, Results, Analysis and Conclusions, Works Cited. A poster and/or oral presentation will also require an Abstract. Use this chapter in conjunction with the proposal chapter (Chapter 5) and the MLA documentation chapter (Chapter 10) to keep the writing process moving along. Consider developing a writing schedule for each section of the paper so that you are not cramming too much writing into a single weekend or evening (see Appendix A, pp. 191–192). Also, add some extra time to your schedule so that a classmate can do a peer edit of your paper and you can make adjustments based on that edit before turning in a final copy to your teacher.

If working with others on your STEM research project, agree on tasks for each group member, as you have done at previous stages of the project. Document the discussion in a contract that each member signs, then turn the contract in to your teacher.

The next chapter will help those of you who will be presenting your research to your classmates or to attendees at a symposium or fair.

Reference

Day, R. A., and B. Gastel. 2006. *How to write and publish a scientific paper.* Westport, CT: Greenwood Press.

Recommended Resources

George, M. W. 2009. *The elements of library research: What every student needs to know.* Princeton, NJ: Princeton University Press.

International rules for precollege science research: guidelines for science and engineering fairs. 2010. Retrieved March 16, 2011, from Society for Science and the Public, Intel ISEF document library website: *http://apps.societyforscience.org/isef/rules/rules11.pdf*.

MLA handbook for writers of research papers. 7th ed. 2009. New York: Modern Language Association of America.