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ABSTRACT

Students' writing skills develop with their reading skills. Here I provide a five-step approach to reading a paper, and four criteria (the "four C": content, clarity, coherence, and craft) to structure writing and revising of a manuscript. I used these in a sophomore course on plate tectonics. In the first part of the course students read and summarized original papers, while in the second part they synthesized a contentious or recently resolved issue. Both parts stressed the importance of revising drafts. During the course, feedback on drafts and revisions shifted from comments by the instructor to comments by peers. An assessment of the course from student evaluations, colleague feedback, and Writing Center comments, indicates that students' writing did improve. Students acknowledge that careful reading helps them become better writers.

INTRODUCTION

College educators place more and more emphasis on students developing writing skills (e.g., Davis, 1993), and so do students (e.g., Light, 2001). In the Earth Sciences, this need has given rise to new methods of writing assessment (e.g., "argumentation analysis model"; Takao et al., 2002) and new courses (e.g., "Geocommunication"; Lewis and Wolf, 2003). However, good writing can only develop in conjunction with careful reading.

Gopen and Swan (1990) dissect writing samples from the readers' point of view. They show how readers expect information to be conveyed through certain grammatical structures. They also argue that "dysfunctional structure" may be traced to the writer's thoughts being clouded, leading to misintepretations on the readers' part. In Gopen and Swan's words: "it may seem obvious that a scientific document is incomplete without the interpretation of the writer; it may not be so obvious that the document cannot 'exist' without the intepretation of each reader" (Gopen and Swan, 1990, pg. 558). If we accept this proposition, then we have to conclude that helping students write more proficiently cannot be accomplished without also teaching them read more effectively.

In this paper my central argument is that critical reading is the foundation to meaningful writing. In fact, reading and writing advance together. I will show how I implemented these two aspects of scientific discourse in a sophomore level course on plate tectonics. I think that the tools used are applicable to other courses.

STEPS TO WRITING A SCIENTIFIC PAPER

The goal of scientific writing is to convey information which often is extracted from papers. Reading is therefore a necessary first step, and showing students how to read critically will in turn show them how to write successfully. Equally important is revising of a draft; luckily, similar criteria can help in writing and in revising a paper.

Reading - Unlike reading a novel for pleasure, reading a scientific paper is aimed at understanding concepts and answering questions. My handout (Table 1) provides students with a framework for this task, from quickly skimming a paper to carefully summarizing it. Students realize with the help of this handout that most readers have specific questions in mind. They acknowledge that most readers will scan a paper before deciding to either read it in detail, or focus on certain sections, or not read it further. They realize that certain elements (title, abstract, conclusions, topic sentences, figure captions) are crucial to make this decision. They thus gain insights that will help them with their own writing. Having extracted information and structured it in point form or as diagram/concept map (e.g., Englebrecht et al., 2005, and references therein) they are ready to proceed to the next step.

Writing: the "four C" - Jewelers grade diamonds and other gemstones using "four C": carat, clarity, colour, and cut. Students and instructors can evaluate scientific writing using similar "four C": content, clarity, coherence, and craft (see Table 2). Content characterizes the information of a text. Clarity is obtained by carefully choosing words (expecially strong verbs, see Mahrer, 2001b) and aligning the meaning of a sentence with its grammatical sequence (Mahrer, 2001a). Coherence is established by logical flow of information, how sentences are linked into paragraphs, and transitions (Mahrer, 2001c; 2001d; 2005). Craft, often called mechanics (see, e.g., Colorado College, 2005), includes punctuation, spelling, and grammar. The "four C" allow students to structure the writing process. For example, a flow chart, concept map or list of information obtained through careful reading can be sorted into a logical - that is coherent - progression, and strong words can be extracted from this compilation for maximum clarity.

Revising - This step "might be considered the most important stage of the whole writing process" (Leahy, 2002, pg. 52). Unfortunately, students commonly underestimate time and effort needed to advance their preliminary draft to a readable manuscript. The "four C" can help them, because they can break up the revision of a draft into four logical passes, each focussing on one C. On purpose I avoid distinction between revising and editing; the first typically means changing content, while the second is synonymous with working on craft. Coherence and clarity are left out in this distinction, or rather are implicit in the term revising. The "four C" allow for a more guided approach, prompt students to be more specific, and emphasise writing with a reader in mind.

To clarify the usefulness of the "four C" in revising, I provide an example. Here is the first draft of a summary (Jacoby, 2001; see Table 3) a student brought to class:

> Alfred Wegener forms a working hypothesis of continents and ocean basins in "The origin of the continents" (1912). He dismisses the old theory of

The following is a 5-step approach to reading a scientific paper. These strategies are applicable to this course, as well as when you do literature research for a project.

1. Skim : fast first reading focus on title, abstract, intro, ..., conclusions body: "read diagonal", i.e. topic sentences, figures	→ what are the objectives and key points of the paper?
2. Reflect : what is the hypothesis being tested what about data acquisition / use of data?	→ does it relate to my question?
3. Re-read : focus on points important to you underline and take notes (you may need to skim additional papers that are cited)	→ which information is important for me?
4. Critique : good argumentation weak points, no data support, ...	→ are conclusions logical? is the paper easy/hard to follow?
5. Summarize : as text / diagram / concept map basic points, questions addressed, approach taken, important data, questions not answered: not every detail	→ neither simply a summary nor simply a critique, how could I improve on the study?

Table 1. Paper-review strategies.

vertical movement of land connections in favor of a new theory of horizontal movement of continents in oceanic crust (continental drift). To support his argument, Wegener presents geophysical and geological evidence, historical geology, and calculations of present movement from astronomical observations. Wegener suggests that seafloor rocks are denser than the continents, explaining their lower elevations. Gravity measurements confirm this, as there is no anomaly as would be expected if the seafloor were the same density and thickness as continental crust. [...] Wegener argues that the "sima", or ocean-floor rock, is more plastic than the "sial", or continental rock, thus making it possible for continental rafts to "drift" though the seafloor. [...] Finally, Wegener performed calculations based on historical latitude-longitue readings and concluded that continents drift at a rate of about 4 km/yr. Wegener concludes by noting that this is only a working hypothesis and requires further testing and rigorous calculations.

Wegener dismisses the old theory of vertical movement of land connections in favor of a new hypothesis of horizontal movement of continents through oceanic crust (continental drift). The continental drift hypothesis is supported by geophysical, geological, and paleobiological evidence, as well as by calculations of present continental drift rates from astronomical observations. Gravity measurements suggest that seafloor rock is denser than continental rock, explaining its lower elevation. If the ocean-floor rock is also more plastic than the continental rock, it is possible for thicker, lighter continental "rafts" to "drift" through the thinner, denser seafloor. [...] Finally, repeated astronomical positioning show that Europe and Greenland are currently separating at a rate of about 4 m/yr. However, Wegener cautions that continental drift is only a working hypothesis which requires further testing and more rigorous calculations to become a theory.

In small group discussions, followed by a plenary session, the class noted the following:

content - 4 km should be 4 m; what do you mean by "historical latitude-longitude readings";
clarity - sentences are repetitive (most subjects are "Wegener"); which are key words?
coherence - second sentence would make for a better topic sentence; how can you show threads more obviously?
craft - few obvious flaws (second to last sentence switches to past tense)

The student then submitted the following revised version:

I think this revision flows better because it conforms to the "four C".

THE COURSE

"Plate Tectonics" was taught at the sophomore level. This is a critical point in the training of future Earth scientists, now students begin reading primary literature and developing their scientific writing skills. I tought the course twice at Colorado College, which is renowned for its block-plan teaching in which only one subject is taught in a 3-and-1/2 week unit. An advantage of this was that I was able to freely schedule time and take students off-campus; an advantage of a semester-long

content:
- no errors in science
- writing is focussed
- writer has readers in mind
- writer guides readers from problem to solution

clarity (of sentences):
- keep sentences short
- choose meaningful words
- use specific verbs
- avoid nominalizations
- align the two levels of a sentence:
  - grammar (subject + verb + complement)
  - meaning (characters + action)

coherence (of paragraphs and whole text):
- strong topic sentences
- consistent threads -- from the known to the unknown
- help reader from one sentence to the next
- passive voice and nominalizations may be useful

craft:
- correct syntax, grammar, punctuation, spelling
- correct citations

Table 2. The "four C" of (scientific) writing.

course would be that students can put drafts aside for a while.

My stated course objectives were:

At the end of this course, students will be able to:
(1) explain the evidence that supports the plate tectonic theory,
(2) describe current thoughts and unexplained problems,
(3) critically read and evaulate a scientiric paper, and
(4) present scientific thoughts orally and in writing.

The first part of the course (10 sessions) was devoted to reading and summarizing papers. These were chosen for their wide range in topics and writing styles, the complete list is shown in Table 3. The earliest paper (Wegener, 1912; in a thoughtful translation from German into English by Jacobi, 2001) is suprising for the wealth of arguments given in support of continental drift, many of which are often not attributed to Wegener. Several of the following papers were published in the 1960's, when arguments in favour of the plate-tectonic theory were proposed in rapid succession. More recent papers were noticeable for their clear organization: they start with an abstract and are divided into sections marked by headings. Students noticed how such structuring of a paper helped them find key arguments.

At our first meeting, students were handed a copy of the papers and a handout on strategies for paper review (Table 1). Each of the following sessions was devoted to one or two papers, and modeled the paper-review strategies. A student might read aloud the topic sentences (step 1: skim). Students would discuss how this paper relates to the course topic and what information they found essential (step 2: reflect). My stated role was that of a facilitator, that is I would guide their inquiry through questioning, referring them to key paragraphs, and having them rephrase each others' thoughts. However, I sometimes had to explain important concepts. For example, Muttoni et al. (2001, see Table 3) tightly word the "paleomagnetism" section with an expert readership in mind; students cannot understand this section without prior knowledge of paleomagnetic methodology like field tests, demagnetization techniques, and paleopoles. In some cases I asked students to analyse a key paragraph in more detail, underline subjects, verbs, or topics and determine whether these conveyed key information (step 3: re-read, and step 4: critique). Accompanying students' discussion of the paper, we would create a diagram on the blackboard (step 5: summarize). Sessions also included discussions of writing issues (Table 2), complemented by papers like Gopen and Swan (1990) and the column "Writer's Block" by Kenneth Mahrer published from 1998 to the present in "The Leading Edge".

Students wrote a one-paragraph summary of the paper as a homework assignment, to be handed in at the next session. After that session, I would go over each summary, point out flaws in the argumentation as well as problems in the organization, and give some suggestions for improvement. We would also discuss student summaries in class. Students then resubmitted their summaries. In some cases I would ask for a second revision, or suggest the student take it to the Writing Center for language editing. Thus each paper was submitted two or three times. This process was time consuming for students and myself. The small class size allowed me to give feedback on drafts and revisions. Students become more aware of flaws in the structure once they are more comfortable with the content. If they are able to place the original and the final versions of a summary side by side they have an immediate sense of accomplishment.

While revising their writing, students may realize that they have "misread" an important concept. This demonstrates how reading and writing develop together. The written summary can be regarded as a test of how well the student has read a paper. At the same time, the act of writing will sharpen the student's awareness of structures used by good writers to guide the reader. By discussing a draft with an individual student or with the class, an instructor can draw attention to dysfunctional structures and demonstrate how they may lead to misinterpretations. Because students also take the roles of active readers, they sense the necessity of writing with the reader in mind.

At this time students entered the second part of the course, in which they had to prepare and present a review on an issue that is either contentious or has only recently been solved. Clearly, this required them to not only present information, but to synthesise maybe opposing viewpoints from different papers. I developed a selection of topics (e.g., mantle convection, formation of crust, intraplate deformation, true polar wander, interactions between tectonics and climate, plate-driving forces, absolute plate velocities) in consultation with colleagues. Guidelines on how to structure a paper, the purpose of different parts (title, introduction, conclusion), and how to reference were handed to students together with a few papers to start their research. Students were required to find more papers in the library and from databases. With an outline of how they would like to present their findings they had to meet me to ensure there were neither misconceptions nor

1) overview and historical context
Frankel, H., 1988. From continental drift to plate tectonics (commentary), Nature, vol. 335, pg. 127-130.
2) early geological and geophysical arguments
Jacoby, W. R., 2001. Translation of Die Entstehung der Kontinente by Dr Alfred Wegener, Journal of Geodynamics, vol. 31, pg. 29-63.
3) mid-ocean ridges (two short papers)
Wilson, T., 1965. A new class of faults and their bearing on continental drift, Nature, vol. 207, pg. 343-347.
Sykes, L. R., 1969. Seismicity of the mid-ocean ridge system, Geophysical Monograph, vol. 13, pg. 148-153.
4) seismology and mantle convection
Karason, H. and R. D. van der Hilst, 2000. Constraints on mantle convection from seismic tomography, in: The history and dynamics of global plate motions, edited by M. A. Richards, R. G. Gordon, and R. D. van der Hilst, Geophysical Mongraph, vol. 121, pg. 277-288.
5) tectonics on a sphere
McKenzie, D. P. and R. L. Parker, 1967. The North Pacific: an example of tectonics on a sphere, Nature, vol. 216, pg. 1276-1280.
6) paleomagnetism 1 (sea-floor anomalies and magnetic stratigraphy)
Vine, F. J., 1966. Spreading of ocean floor: new evidence, Science, vol. 154, pg. 1405-1415.
7) paleomagnetism 2 (paleomagnetic poles and APW paths)
Muttoni, G., E. Garzanti, L. Alfonsi, S. Cirilli, D. Germani, and W. Lowrie, 2001. Motion of Africa and Adria since the Permian: paleomagnetic constraints from northern Libya, Earth and Planetary Science Letters, vol. 192, pg. 159-174.
8) determining plate velocities
DeMets, C., R. G. Gordon, D. F. Argus, and S. Stein, 1990. Current plate motions, Geophysical Journal International, vol. 101, pg. 425-478.
9) plate-driving forces
Lithgow-Bertelloni, C., and M. A. Richards, 1995. Cenozoic plate driving forces, Geophysical Research Letters, vol. 22, pg. 1217-1320.
10) plate tectonics and local geology
Maxson, J., and B. Tikoff, 1996. Hit-and-run collision model for the Laramide orogeny, western United States, Geology, vol. 24, pg. 968-972.

Table 3. Reading list for first part of Plate Tectonics course.

omissions in their outline. During an off-campus workshop a few days later they presented their topic to the class followed by a discussion. This ensured that students had a good grasp of the material, could convey the content to their peers, and gave them a chance to mend any uncertainties. For the abstract I directed them to the paper by Landes (1951). Manuscripts were then submitted to me, and students engaged in a peer-review process similar to the one described by Lewis and Wolf (2003). I guided the review by handing each student two papers to review and providing specific questions (Table 4) that I modeled after an actual review sheet from the "Canadian Journal of Earth Sciences". These questions point to typical problems and provided criteria for marking each paper. By critically reading each other's papers, peers were learning about an unknown topic. I collected the reviews, and before returning them, I asked students to complete these statements:

(1) What I like about my paper.
(2) I think the following still needs work.
(3) What I learned about the writing process and myself as writer.

This reflection served two purposes. First, it forced the students to evaluate their own paper. Often students' self-evaluation is remarkably honest and valuable, and self-evaluation is an important skill (Fenwick and Parsons, 2001). Second, it helped me to grade the papers, because I could briefly comment on the reflection without having to write those comments myself (Leahy, 2002). In order for students to submit revised manuscripts for grading, I provided them with an electronic paper template they had to follow. The collection of papers was then "published" in a "special volume". Course grades were based on evaluations of the final papers, grades for the revised summaries, and feedback to peers.

ROLE OF THE WRITING CENTER

The Writing Center plays an important role in helping students acquire the skills they need to write a coherent paper. Yet, I think the assistance of the Writing Center can easily be overestimated. Many instructors, for lack of time, will direct students early to the center for help. At Colorado College (and I assume this to be true at many institutions), most staff and volunteers at the Writing Center have majored or are majoring in languages or arts. They are not experts in the course topic and thus cannot be expected to provide content editing, let alone help students with the reading process that preceeds any writing. However, they can spot obvious language errors and give valuable feedback during a late revision step,

Manuscript:_____ Author:_____
Please answer the following questions critically. Do not just answer "yes/no", but provide helpful suggestions. Use a separate sheet if necessary.

Content

Is this paper worth reading?

Is this paper scientifically correct?

Is the method easy to follow?
Do the data support the conclusions?
Do arguments follow logically?

Organization and presentation

What do you think is the main point of the paper?

Are key points emphasized?

Is the organization of the paper acceptable?

Could the paper be shortened?

Can the title be improved to better reflect content of the paper?

Does the abstract catch the essence of the paper?

_____

please do not write below this line

Have all the pertinent (and only pertinent) references been cited?

Can the tables and illustrations, including captions, be improved?

Do figures link to the text and clarify concepts?

Are figures easy to read (size, axis labels, large enough font, ...) ?

Language

Do you find any problems in grammar, syntax, or spelling?

Are sentences clear and paragraphs coherent?

Is there an economy of words and is the paper easy to read?

Overall appraisal

What is the weakest part of the paper?

What is the strongest part of the paper?

In your opinion, this manuscript is

- O acceptable as is
- O acceptable after minor revisions
- O acceptable after moderate revisions
- O acceptable after major revisions
- O unacceptable

_____

You may reveal my identity to the author: O yes O no
Name:_____ Date:_____ Signature: _____

Table 4. Sheets with peer-review questions.

once the student has understood the topic and is struggling with fine-tuning grammar and structure. In addition, for the Writing Center to be of most benefit to the student seeking help, instuctors need to allow the students sufficient time to revise their paper before heading to the center. Therefore, instructors have to be very clear about what role the Writing Center should play in their courses.

EVALUATION

In this section I present anecdotal evidence from students, colleagues, and Writing Center staff that the course was effective.

Students could assess their own progress by comparing draft and final version of summaries and papers which they kept in a writing portfolio. In their written course evaluations, they commented positively on most aspects of the course. Negative comments were limited to "harsh grading". Here are some of their remarks: "I think the emphasis on writing and use of papers with often opposing views forces more critical thinking than a text-based course." "I really liked the writing workshop/discussion format and found it very helpful. The handouts on technical writing were great, and I felt that I got a good overview of plate tectonics from the journal readings. I wish I could have taken this course earlier, and I think most geo majors would benefit from serious instruction on scientific writing." "I would rather learn than work on writing, but more work on writing was good for me." The evaluation asked students to name one key aspect about writing that they learned and will not forget: "Be concise, connect sentences together." "Putting new, complex ideas at the end of a sentence." "Have others edit my work!" "Peer reviewing is extremely valuable." I think all these comments show that my course objective of improved ability to critically read and evaluate a scientific paper was met. Furthermore, students valued reading as an important skill, and pushed themselves to become better writers. They recognized important concepts of clarity and coherence. Not surprisingly, they respected help from their peers. One student noted: "I expect that all I learned this block will help me succeed, not only next year, but as I pursue [...] future endeavors." Indeed, reading and writing are key skills students should take with them from a college education.

Not only students appreciated my efforts. Earth science colleagues noted that my course was effective. For example, Jeff Noblett (professor at the Department of Geology at Colorado College) wrote: "students have been very appreciative and the ones I have seen after the class showed dramatic improvement in their skills." Early last fall I also presented student writing samples to Krista Caufman, then the director of the Writing Center at Colorado College. She agreed with my assessment of these being good to excellent. We discussed my philosophy of the course, and she suggested to the director of the Writing Program at Colorado College that this course should be offered in spring as an "Emphasis on Writing Course". My course thus became one of only two natural sciences courses at Colorado College to be offered with this designation.

OUTLOOK

If instructors want to help students develop good writing habits, we need to show them examples of good and poor writing and help them read and understand what constitutes good writing. I have presented guidelines for a seminar-style course that combines teaching about a subject with reading and writing about it. Overall, I was pleased with the outcome of this course. Although my course was small (7 students) I think that even in larger classes (20 to 30 students) it is necessary to give each student individual feedback on early drafts. This will not be possible in very large classes. Here I would not suggest having students write review papers on contentious issues; selecting topics, finding papers, and meeting with individual students would be impossible for one instructor in the given timeframe. However, peer review is a powerful avenue of engaging a large class in writing exercises. For example, an instructor could ask students to summarize a paper in one paragraph and in the next class use one sample to show how the writing can be improved. Students then could review each other's work. This task can be facilitated by providing them with clear criteria like the "four C". Such criteria may be expanded on and handed to students - and teaching assistants - in the form of a "Primary Trait Analysis" (for an explanation and examples I refer to Leahy, 2002, and Walvoord and Anderson, 1998). This will help them develop their own writing, and with it their own reading skills.

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REFERENCES

Colorado College, 2005, Writing evaluations, http://www.coloradocollege.edu/learningcommons/writingcenter//evaluations.asp (25 July 2005).

Davis, B. G., 1993, Tools for teaching, San Francisco, USA, Jossey-Bass Publishers, 429 p.

Englebrecht, A. C., Mintzes, J.J., Brown, L.M., and Kelso, P.R., 2005, Probing understanding in Physical Geology using concept maps and clinical interviews, Journal of Geoscience Education, v. 53, p. 263-270.

Fenwick, T. and Parsons, J., 2000, The art of evaluation, Toronto, Canada, Thompson Educational Publishing, 244 p.

Gopen, G. D., and Swan, J.A., 1990, The science of scientific writing, American Scientist, v. 78, p. 550-558.

Landes, K. K., 1951, A scrutiny of the abstract, Bulletin of American Association of Petroleum Geologists, v. 35, p. 1660.

Leahy, R., 2002, Conducting writing assignments, College Teaching, v. 50, p. 50-54.

Lewis, R. D., and L. W. Wolf, 2003, Gecommunication, a cornerstone graduate course in professional development, Journal of Geoscience Education, v. 51, p. 244-249.

Light, R. J., 2001, Making the most of college: students speak their minds, Cambridge, USA, Harvard University Press, 42 p.

Mahrer, K. D., 2001a, Clearer sentences - part 1, The Leading Edge, May 2001, p. 547-548.

Mahrer, K. D., 2001b, Clearer sentences - part 2, The Leading Edge, June 2001, p. 662-663.

Mahrer, K. D., 2001c, Cohesive paragraphs, part 1, The Leading Edge, August 2001, p. 839+867.

Mahrer, K. D., 2001d, Cohesive paragraphs, part 2, The Leading Edge, October 2001, p. 1128.

Mahrer, K. D., 2005, The threads of writing, The Leading Edge, January 2005, p. 42.

Takao, A. J., Prothero, W.A., and Kelly, G.J., 2002, Applying argumentation analysis to assess the quality of university oceanography students' scientific writing, Journal of Geoscience Education, v. 50, p. 40-48.

Walvoord, B., and Anderson, V., 1998, Effective grading: a tool for learning and assessment, San Francisco, USA, Jossey-Bass Publishers, 249 p.