A Cognitive–Apprenticeship–Inspired Instructional Approach for Teaching Scientific Writing and Reading

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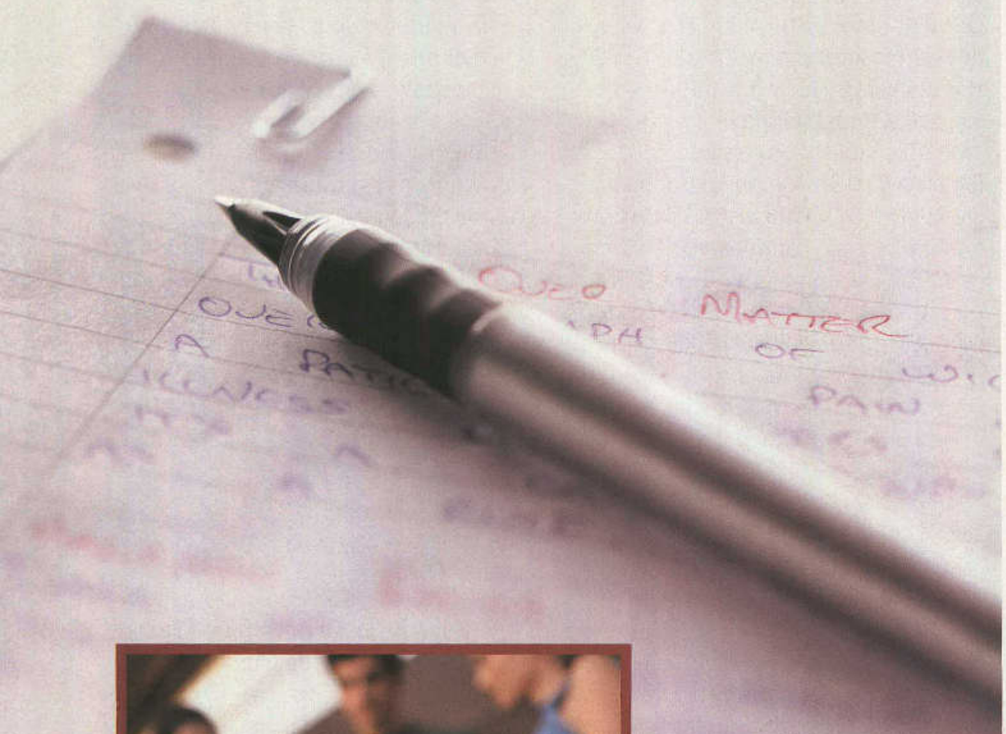
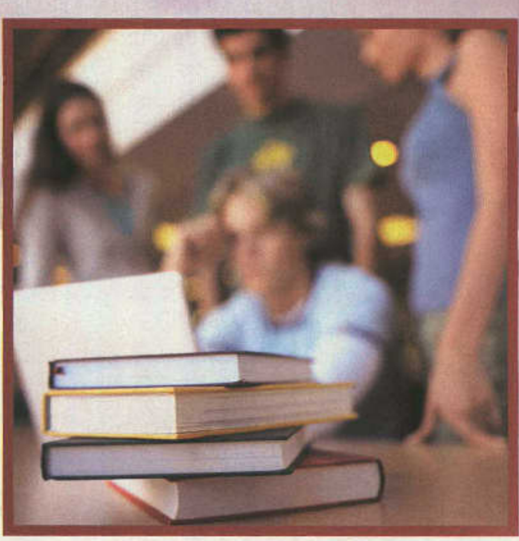
We present an approach for integrating instruction of scientific writing and reading into undergraduate science courses, inspired by the pedagogical theory of cognitive apprenticeship. We demonstrate its implementation and describe a study of students' feedback that enabled us to elicit students' difficulties and fine-tune the next application accordingly.





Reading and writing scientific literature is an indispensable part of a scientist's work. Specifically, scientific literature is arguably the most important communication channel within the scientific community, making available for practitioners the collective wisdom and knowledge of the community (Koprowski 1998; Rice 1998). We believe that one of the objectives of higher education in science and engineering is to introduce students to the process of scientific research and, correspondingly, to introduce students to the importance of reading and writing scientific literature for their professional lives.

Much work has led to the development of diverse approaches for integrating reading, writing, and presenting of scientific literature into science and engineering courses. Working with the literature can serve as a means to achieve a variety of goals, such as improving conceptual understanding (Auerbach, Bourgeois, and Collins 2004; Janick-Buckner 1997) and enhancing communication skills (Glaser 2000; Koprowski 1998; Rice 1998). There are different approaches to teaching communication skills. At some universities there are separate courses taught by instructors with either scientific backgrounds (Rice 1998) or with contrasting backgrounds in writing, English, and communication (Chisman 1998), whereas at other universities, instructors integrate the teach-

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ing of communication skills into their science courses. Students' assignments involve writing scientific biographies, papers (Smith 2001), proposals (Felzien and Cooper 2005), peer reviews (Koprowski 1998), and reviews of scientific papers (Glaser 2000; Chisman 1998).

However, writing is a particular form of problem solving (Berkenkotter 2004; Flower and Hayes 1997). Novice writers, such as students, typically begin writing hoping that they will serendipitously articulate the "right" sentence(s), which will carry them through the whole written draft. In contrast, experts use sophisticated strategies, such as setting and resetting writing goals, generating ideas, exploring relationships among the ideas, and finally connecting them in some kind of analytic framework aimed at a specific reader. Practice and assignments alone will not turn novice writers into expert writers. Students need scaffolded instruction, as well as experience, to master higher-level skills in writing such as synthesis and argumentation (for more information, see the extensive literature on Writing Across the Curriculum, e.g., Berkenkotter 2004; Bazerman and Russell 1994).

Therefore, we present an integrated approach to teaching students to read, understand, and write scientific literature. The approach is based on the cognitive apprenticeship instructional model (CAIM), which exposes students to the thinking processes that professionals carry out in professional tasks, and allows them to experiment with expert strategies while mentored in an authentic context (Collins, Brown, and Holum 1991; Collins, Brown, and Newman 1989). The CAIM has been implemented successfully in other domains such as teaching mathematical problem solving (Schoenfeld 1987), and teaching reading and writing (Bereiter and Scardamalia 1987). (For more examples, see Wilson and Cole 1991.) We describe how this approach was used in a junior-level animal physiology class.

The cognitive apprenticeship instructional model (CAIM)

In the CAIM, teaching consists of the following methods:

- Modeling—an expert performs tasks while reflecting on the thought processes involved, thereby making these processes visible to apprentices.
- Coaching—an expert observes students carrying out a task and provides scaffolded instruction.
- Articulation—students articulate their knowledge, reasoning, and problem-solving processes.
- Reflection—students compare their work to that of the expert.
- Exploration—students are encouraged to solve problems on their own.

Designing an instructional activity based on the CAIM requires analyzing an expert's knowledge beyond that of content and focusing on the expert's activities, as well as heuristics and strategies gained by experience. CAIM is well suited to writing instruction in college science classes because higher education brings together students, who are novice writers, with faculty, who possess expert knowledge, such as discipline-specific writing conventions and where and how to search for scientific literature. In addition, faculty possess important cognitive skills, such as analysis and synthesis, to manipulate knowledge. *Analysis*, when associated with scientific literature, involves understanding how others contributed to a research question, identifying whether the evidence supports the authors' claims, and assessing whether the authors' methods are valid. *Synthesis*, according to Bloom (1956), refers to creating a new idea by combining information from different sources, and in scientific writing involves reorganizing one's own knowledge, and that of others, to answer the research question. In theory, a CAIM-inspired approach should benefit novice writers because they can reflect on their own approach to writing and develop their critical-thinking and writing skills, having seen how an expert engages in analysis and synthesis. Yet, coaching and modeling require theoretical knowledge and pedagogical practices that are not typically part of a science instructor's repertoire.

Our instructional approach

The assignment

To teach the process of scientific reading and writing in a context that resembled authentic scientific work, students were assigned a scientific paper. Under the general topic of "animals' adaptations," students were asked to (1) choose an animal with a physiological ability not possessed by humans (e.g., hibernation, infrared sensation), (2) analyze two to four articles from the research literature on this topic, and (3) compare the function of this system with analogous systems in other species, including humans. Because we wanted students to focus on tasks associated with the literature, the assignment did not include laboratory experiments and thus the papers did not include an empirical part.

Students began by writing a research proposal including (1) a research question, (2) a paragraph describing their interest in the topic, and (3) two to four references to be used to answer the question. The proposal was submitted to the instructor and to two peers for review. Instructor feedback helped students examine the validity and feasibility of the proposed work. The peer review provided students an opportunity to reflect upon their own work and to play the role of reviewer common in the scientific community. Next, students had three weeks to write their papers.

The scaffolding

We divided the anticipated work into tasks and outlined the scaffolding needed for each task in terms of practical information and expert practices. Tasks were provided in various ways, as shown in Table 1. Scaffolding included three documents (D1, D2, and D3) that the instructor posted on the course website and used in two oral discussion sessions (S1 and S2). Also, the evaluation form (E) was posted prior to the assignment's deadline to encourage students to align their activities with our educational goals (Table 3). (These forms can be downloaded from the VaNTH website, *http://www.vanth.org/curriculum/communications.asp*.) Finally, the instructor provided flexible office hours to meet with students about the assignment.

Documents. In document D1 we defined the assignment, provided structure for the proposal and the paper, provided initial guidance (e.g., sample research questions), and listed the future scaffolds. Documents D2 and D3 supported the activities required to write the research proposal and the paper, respectively. Both documents included strategies to direct students to their next activity and to reason through the process. Excerpts like these exemplify the strategies provided:

- "If you have an idea, your problem is going to be making the topic manageable by restricting your focus."
- "If you have a rough idea for a topic, learning a little bit about it before launching into the serious research literature is a good idea."
- "You need to keep your audience [other physiologists] in mind."

Discussion sessions. There were no discussion sessions in this course prior to the described intervention. Therefore, sessions S1 and S2 were made optional. Nonetheless, having a separate session for each topic underscored their importance to the assignment.

S1 helped students search and find literature relevant to their research question. This session was useful, but not innovative. S2 modeled the thought processes of an expert, namely the instructor, and thus was essential to the CAIM. First, the instructor translated the meaning of analysis and synthesis into the practical questions he asks himself when he surveys literature.

Next, he engaged students in an activity intended to illustrate the

TABLE 1

The scaffolding design.

Tasks	Scaffolding	How/where provided		
Composing a research proposal		Discussion session	Documents	Personal feedback
• Finding a topic	1. Examples of research questions	S1	D1	-
	2. Information about journals useful for defining a question (or researching a question)	S1	D2	yes
	3. Strategies for finding a question from the literature	S1	D2	yes
	4. Heuristics for exploring the topic before deciding on the actual resources	S1	D2	yes
• Finding relevant original literature • Getting original literature	1. A list of online field-specific search engines	S1	D2	-
	2. A description of the limitation of general-purpose (nonscientific) search engines	S1	D2	-
	3. A description of the procedure required for retrieving the relevant literature	S1	D2	-
	4. Heuristics used by scientific professionals to read the literature	S2	-	-
• Composing the proposal	1. A detailed structure of the proposal	-	D1	-
	2. Instructions for peer review	S2	-	-
	3. Explanation of experts' criteria for review	S2	-	-
Writing a paper				
• Analysis of the resources with respect to their original goals, as well as to the proposed research question • Synthesis of resources into the answer to the research question • Evaluation of the limitation of the answer	1. Explanations and demonstrations of the meaning and expected outcomes of each of the tasks within the context of scientific reading/writing and the specific writing assignment	S2	D3	yes
• Composing the paper	1. A description of the conventions of scientific writing: structure and mechanics	S2	D3	-
	2. Class activity to demonstrate the conventions in scientific literature	S2	-	-
	3. An explanation of the gap between genuine scientific papers and students' papers, and the pedagogical reason underlying this difference	S2	D3, E	-
	4. Additional resources such as books and e-books that support writing	-	D3	-

structure and benefits of writing conventions used in physiology. To this end, he brought scientific papers to the class. Each student selected a different paper. They read the headings aloud as the instructor, in turn, wrote them on the blackboard. Obviously, most of the papers had similar headings, e.g., abstract, introduction, methods, results, discussion, and conclusions.

Students were then asked to outline the content of each section, guided by questions such as, "What should you expect to find in the introduction?" The instructor organized these responses on the blackboard, outlining the contents of each of the paper's headings.

He also directed students' attention to writing norms. For example, results are typically organized around the figures and tables, while the discussion usually includes few, if any, figures. Moreover, within the discussion, he was able to demonstrate his familiarity with the journals by guessing correctly, simply from students' descriptions of an article's placement of graphs and tables, which journal had published which article. This was a very dramatic and visible demonstration of how thoroughly professionals master the literature resources in their respective fields.

Finally, in order to ease the process of choosing resources from the literature, the instructor articulated the thinking process he follows when perusing the literature, thereby demonstrating the evaluative nature of this process. He first reads the introduction in order to determine if the paper is relevant to his interest, then reads part of the discussion section to see whether the results support the hypothesis. He then jumps to the results, focusing on the figures and charts because they summarize the important data. Then, if the article suits his interest, he delves into the details and reads the entire section. He scans the methods section, merely verifying the reasonability of the experiments. If an innovative method is offered, his reading will become more thorough and critical. The point of this demonstration was not to show that

TABLE 2

Students' responses regarding the usefulness of the discussion rating each category on a scale of 1 (no importance) to 4 (very important).

Topic	Usefulness			
	To this assignment		To my professional future	
	Mean	SD	Mean	SD
Analysis/synthesis	3.59	0.62	3.56	0.63
Writing	3.47	0.66	3.13	1.08
Reading	3.24	0.66	3.35	0.49

TABLE 3

Evaluation of students' papers (rubric).

Evaluation criteria (maximum points)	Percentage of students penalized for incomplete work (n=22)
1. Content of introduction (17)	
a. Clear explanation of question	23%
b. Explanation of why question is important	5%
c. Appropriate background to explain topic	18%
d. Appropriate use of references	27%
2. Content of literature review (33)	
a. Clarity of analysis of original articles: question or hypothesis, methods, results, conclusions	82%
b. Depth/quality of analysis of original articles	55%
c. Use of figures and/or tables to support explanation of original articles	23%
d. Discussion of points not clear in the original articles, if applicable	0%
3. Content of discussion (25)	
a. Discussion of the limitations of original research articles	23%
b. Synthesis of an answer to the original question	18%
c. Synthesis of suggestions for future work and/or new hypotheses, if applicable	23%
d. Comparison of the animal under discussion to other animals	9%
4. Organization (8)	
a. Coherence of topics discussed	9%
b. Appropriateness of major articles	23%
5. Mechanics (17)	
a. No more than 6 pages, 1.5 line-spaced, 1-inch margins, 11-point or larger font (references, figures, and tables outside this limit.)	0%
b. Legends for figures and tables	18%
c. References in consistent, complete format	27%
d. Spelling, punctuation, grammar	50%
e. Using words carefully and precisely	59%
f. Submission of original articles with your paper	0%
Total (100)	

the instructor's strategy is superior, but rather to demonstrate that professionals have a reading strategy, one which writers need to consider. This is especially true because professionals rarely read papers from beginning to end, and skim a great deal of literature.

Instructor evaluation of student papers

The top of the evaluation form included a shortened version of the assignment. Below that were listed the evaluation criteria for the papers, presented in the left column in Table 3. Grades were awarded to each component of the paper based upon a list of subcriteria that matched the instructions. For example, the introduction was graded according to the following criteria:

- clarity of the question,
- explanation of its importance,
- appropriate background to explain the topic, and
- appropriate use of references.

Additionally, points were given for the overall organization of the paper as well as for mechanical issues, such as punctuation. The instructor wrote additional comments when points were taken off, as well as general comments on the bottom of the evaluation form and local comments in the body of the paper.

Lastly, in both discussion sessions the instructor explicitly explained to students the gap between a professional review and his review of their work in order to help them align their future learning trajectories. Specifically, the instructor eased the demands in the discussion section, in particular the subcriteria 3c and 3d, in which students were asked to evaluate the limitation of their answers and to make their own suggestions, which require a broader knowledge of the field. Therefore, students were penalized solely for ignoring these tasks or for writing unreasonable arguments.

Study design

In order to fine-tune our instruction, we queried students at the beginning of the course about their experience in writing scientific papers, as well as their competency in associated tasks such as searching for resources and citing them appropriately.

To better understand students' need for scaffolding, we asked them to fill out a survey anonymously after the second discussion session. We listed the three parts of that session and asked students to rank the importance of each from 1 (no importance) to 4 (very important) for accomplishing the assignment and for their professional future, and to explain why.

The class had an enrollment of 42 students. We received 17 responses from the 24 students who participated in that session. We calculated the mean and standard deviation of their responses and specified the common reasons as to why certain scaffoldings were found to be useful (or not).

Next, to measure the gap between students' performance and the instructor's expectations (reflected in the rubric), we calculated the average and standard deviation of the grades. We also collected a sample of 22 papers with the instructor's evaluations and extracted the common difficulties.

Findings

Students' prior experience

For 63% of the students, this was their first science course that had a small enough enrollment to allow for a substantial writing assignment. Only 7% had experienced more than two writing assignments. In addition, 40% said they did not know where to look for recent work done on a given topic, 86% did not know where to find citations to a given paper, and about a third did not know what to do in case a paper they needed was not in the university library.

Students' opinions of the CAIM-inspired discussion session

Students' responses to the surveys regarding the usefulness of the second discussion session are summarized in Table 2. The left column specifies the topic discussed, while the second and third present the mean and standard deviation of students' responses on a 4-point scale and the importance of each (1—no importance; 4—very important).

Most students who participated in the discussion session found it useful. It addressed their short-term goals by helping them to accomplish the assignment.

The most common answer to why the discussion session was relevant had the following pattern: "I will [or will not] need it in my professional future as a [profession]." Interestingly, synthesis and analysis were perceived as important for both long-term and short-term goals. However, writing was perceived as less important for the future than for the assignment. The dominant reason, as shown on the surveys, was that students believed that unless their future was in academia, they would not need writing skills. Alternatively, reading was perceived as being more important for long-term goals than for short-term goals, with many students perceiving it as a general skill, important for any scientifically literate profession.

Analysis of students' papers

The average of students' grades on the papers was 91.88 and the standard deviation was 4.48. We concluded that, in general, students performed satisfactorily on this assignment.

The grading rubric and subcriteria allowed us to examine students' writing achievement in greater detail. The average of the sample of the 22 papers we chose to evaluate more closely was 92 and the standard deviation was 4.4. Thus, the sample was representative of the entire population. Table 3 presents results from the analysis of the evaluations of the sample. The numbered headings in the left column designate one criterion, and the maximum number of points that students could score is shown in parentheses. Below each criterion is an expanded list of specific subcriteria. The right column presents the distribution of students who lost points in any of the corresponding subcriteria.

Most students lost points in the area of "content of literature review"—criterion (2) in the rubric (see Table 3). In particular, 82% of the students did not meet the instructor's expectation regarding the clarity of analysis of original articles (subcriterion 2a), and 55% performed unsatisfactorily regarding the depth of the analysis (subcriterion 2b). In contrast, the small number of students who were penalized in the introduction section implies that the scaffoldings of this task were satisfactory.

Additionally, a small number of students' performances were penalized in the discussion sections of their papers. The instructor added verbal comments that pinpointed invalid or incomplete inference chains, such as, "I am not clear to what extent you told us about these," and, "Would this be useful for humans?"

Discussion

The fact that students performed at such a high level on this assignment, given their limited experience and evidence of the difficulties reported in previous work (Troy, Hirsch, and Smith 2004), implies that our approach was useful.

A further analysis of students' performance revealed two major issues that need to be addressed. First, most students found the scaffolding to be useful for the short-term goals of accomplishing the paper assignment; however, a significant number of students believed that the skill of scientific writing is necessary only for a career in research. Such an attitude may have diminished their engagement in this assignment. In the next application, we will address this issue by demonstrating the life cycle of scientific work and the indispensable part played by the literature, as well as the need to communicate clearly in all careers.

Second, many students were penalized for their performance on the section of literature review, yet were able to synthesize an answer to their research question from these papers. This implies that students understood the papers, but did not know how to communicate their knowledge. Thus, we need to fine-tune the scaffolded instruction in this area. In the next phase, we may provide students with questions to assist them with summarizing and critiquing the original literature.

Arguably, there are books that provide the information needed to carry out a writing assignment. However, because the assignment is time-consuming, reading an entire book might deter students rather than help. In our CAIM-inspired approach, the same knowledge was made accessible to students within a relevant context. Furthermore, the instruction included modeling of the instructor's thinking process in similar situations, coaching students while providing feedback, and clear instructions and criteria, thereby demonstrating the importance of these skills to the instructor's own professional life. ■

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Resource

VaNTH ERC—*www.vanth.org.*

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