ABSTRACT
As geoscience educators, we focus on helping students understand technical content and learn to think like geoscientists. Although research substantiates writing as a tool for teaching technical content and disciplinary thinking, geoscience educators often do not integrate writing in geoscience education because of the frustrations and exigencies involved. To address these issues, this paper describes the literature on using writing as a learning tool in both cross-disciplinary and geoscience teaching contexts. Further, we describe our Less is More approach, designed so faculty can spend less time grading student writing and still yield more learning benefits from incorporating writing. This approach involves five strategies, including explicitly integrating assignments with course objectives, designing effective assignments, incorporating process writing, evaluating writing effectively and efficiently, and consulting appropriate campus resources. Results of an initial assessment using this approach with a geoscience course suggest gains in student learning.

INTRODUCTION
As faculty members in geoscience education, we face a quandary with student writing: on the one hand, the quality of their writing is often below expectations— including grammatical sloppiness, poor transitions, underdeveloped or under-supported ideas, or a general inability of our students to write like geoscientists. On the other hand, we are resistant to expand the writing component of our classes because the process of grading writing can seem subjective, inexact, and overly time consuming. Few of us may be enthusiastic about teaching a writing-intensive course or revising one of our courses to become writing intensive. Of course we realize that if we do not provide our students with practice in learning to write like geoscientists, they will have little opportunity to develop such skills. Offloading this responsibility to a technical writing or composition course loses our disciplinary expertise because our content knowledge puts us in the best position to help students understand how disciplinary thinking informs the writing and content of geoscience documents.

This paper addresses these issues and provides another way of thinking about incorporating writing in geoscience education. Our authorial perspectives stem from our disciplinary backgrounds; one of us teaches writing-intensive geoscience courses in a geology and geological engineering department, and the other conducts research and faculty workshops on Writing Across the Curriculum (WAC) and Writing in the Disciplines (WID), particularly in engineering and applied science settings. The impetus for this paper came following one of these faculty workshops, when we recognized that writing in the geosciences could be improved and expanded if we could demonstrate practical, research-based strategies that enhance learning and minimize the labor of preparation and grading. Before demonstrating such strategies, this paper will provide both a general and a geoscience-specific background on writing as a learning tool.

BACKGROUND ON WRITING AS A LEARNING TOOL
The notion that writing is a learning tool is framed by two important areas of research, in WID and in writing and cognition. Generally, WAC programs aim at improving students' higher-order thinking and problem solving skills as well as their ability to communicate ideas. Unlike more transitory educational reform movements, WAC in 2005 celebrates its 35-year anniversary in the US higher educational system (McLeod and Miraglia, 2001; Russell, 2002). Its staying power is attributed to numerous factors, among which is the fact that WAC helped catalyze and develop numerous staples of current higher education pedagogy, including thematically linked cluster courses, learning communities, collaborative learning, and peer tutoring (Maimon, 2001). Also among WAC's most salient attributes is that writing facilitates problem solving and higher-order thinking (Maimon, 2001). While other educational fads have faded from sight, WAC has experienced steady growth. The fledgling WAC efforts that began in 1970 were widespread by 1988, when approximately 50% of all US postsecondary institutions had WAC programs, a percentage that continues to rise (McLeod, 1989; McLeod, 1992; Russell, 2002; Walvoord, 1996).

As a complement to and often functioning within WAC, WID efforts focus on writing within each discipline or subdiscipline and have several research-based premises:

• That when used appropriately, writing involves active learning and student-centered instruction (McLeod and Miraglia, 2001).

WID is also premised on the notions that "writing expectations and performances are discipline specific," that "much of what an accomplished writer knows about writing is tacit knowledge," and that this "tacit knowledge is conveyed largely via apprenticeship" (Northern Illinois University, 2003). Such premises reinforce the idea that geoscience educators are in the...
best position to prepare students for their professional writing responsibilities by guiding students' understanding of geoscience writing. This paper facilitates that process by providing geoscience faculty with a conceptual framework on writing as a learning tool as well as practical ideas for using writing to facilitate learning in geoscience courses.

Writing facilitates learning in numerous ways. Long-standing research on writing and cognition indicates that writing facilitates higher-order thinking and the learning of content in any discipline (e.g., Britton, 1970, 1993; Britton et al., 1975; Emig, 1977). Reviews of qualitative WAC and WID studies indicate that although writing is not the appropriate learning tool for students doing traditional fact-based learning, it is well suited to more open-ended problem solving (Russell, 2001; see also Ackerman, 1993). One key advantage of WID is that "students must pick up not only textual features as they learn to write, but also the ways specialists think..." (Russell, 2001, p. 264). Indeed, because disciplinary writing is shaped by discipline-specific habits of mind and methods of inquiry, teaching students to write like geoscientists is inherently interrelated to teaching them to think like geoscientists. A review of 35 research studies on writing as a learning tool indicates mixed results, with studies suggesting that in concert with other factors, writing can foster concept synthesis and introduce students to a disciplinary community (Ackerman, 1993). More recent research on writing to learn science has accentuated the learning benefits for secondary students (e.g., see Hand et al., 1999; Keys, 2000; Keys et al., 1999; and Rivard and Straw, 2000). When implemented appropriately, writing has been associated with multiple learning gains, such as making increased conceptual connections, recognizing one's own knowledge gaps, distinguishing between claim and evidence, and metacognition (Hand et al. 2004). Learning gains have also been noted among university students using writing to learn science (e.g., Ellis, 2004, Klein, 1999, and Robertson, 2004), especially when certain instructional practices are in place (Ellis et al., 2005).

Research on the cognitive processes associated with writing also substantiates the complexity of the task of writing. Writers tax multiple cognitive resources as they shuttle between long-term memory, where they store content, audience, and writing knowledge, and short-term memory, where they store planning, translating, and reviewing processes (Flower and Hayes, 1984; Hayes, 1996). This and other research also indicates that effective writers do not possess content knowledge alone, but combine this with knowledge about discourse—about the ways of inquiring, reasoning, and communicating that are common among professionals in a given field (Berente and Scardamalia, 1987; Berkenkotter et al., 1988; Hayes, 1996).

Despite the evidence linking writing and learning, barriers to successfully incorporating writing remain, and many stem from the normal struggles of students and faculty. Research and our own teaching experiences indicate that students struggle with understanding many aspects of writing assignments, especially understanding new genres (including genre-specific purposes, audience expectations, and more) as well as new content (e.g., Berkenkotter, et al., 1988). As mentioned above, faculty often struggle with the time involved and inexactness associated with grading, and some may think the benefits of assigning writing do not outweigh the associated costs.

Yet writing can, instead, serve as a way of addressing both student and faculty struggles and as a tool to facilitate learning of geoscience course content.

WRITING AS A LEARNING TOOL IN GEOSCIENCE EDUCATION

The use of writing as a learning tool in the geosciences is abundantly documented. Sands (2004) provides a bibliography of 15 writing across the curriculum publications, and an entire issue of the Journal of Geologic Education (vol. 39, no. 3, 1991) is devoted to ‘writing assignments as a tool for teaching and learning geology.’ These and other writing-in-the-geosciences publications may be grouped into three categories: those that present evidence of the effectiveness of writing as a learning tool, those that present general writing techniques to be used in a variety of classes, and those that present writing assignments and projects specific to a single class.

For example, the importance of writing is documented by Halsor et al., (1991), who conclude that writing intensively in a course

- Helps students synthesize and articulate geological concepts
- Builds their confidence and ability to write
- Gives them a more thorough understanding of laboratory topics
- Helps them understand the applicability and limitations of laboratory techniques

Likewise, Yelderman and Hayward (1991) and Macdonald and Conrad (1991) present example writing assignments and argue for the benefits of writing and communication skills in general. Mirsky (1991) advocates a continuum of writing assignments across the geoscience curriculum, starting with a sophomore-level technical writing course.

The general technique of journaling is described in Clemons (1991) and Coles (1991). Abstracting is proposed to develop concise writing styles in Davis (1991), and general report writing skills are discussed in Mirsky (1977).

Class specific assignments may be found for introductory geology (Halsor et al., 1991; Peters, 1996; Macdonald et al., 1992; Macdonald, 1991; and Davis et al., 1991), historical geology (Schneiderman, 1991), environmental geology (Mango, 2000; Santi, 2000, and de Caprariis, 1996), field geology (Santi and Laudon, 2002), and hydrogeology (Tinker, 1986), among others.

These examples of writing in the geosciences all focus on the benefits of writing and the methods of assigning it. The techniques that follow are aimed at maximizing the learning experience while limiting the need for major course reorganization and for an increase in faculty time commitment over the long term.

LESS IS MORE

To meet these goals, we suggest an approach in which 'Less is More' or L = M. In general, this idea indicates that we can spend less time grading student writing and still yield more learning benefits from incorporating writing.

The L = M concept can be rendered clear through a discussion of five key strategies for integrating writing into technical courses: assignment integration,
assignment design, writing to learn, writing evaluation, and campus resources. An overview of the relative utility of these strategies in relation to common faculty goals for writing-intensive courses appears in Table 1. Although we can enact each strategy sequentially, these steps do not have to be followed rigidly; many of us are more holistic than systematic in our approaches to course design, and we should follow our current practices if they are efficient and effective. Regardless of our current course design processes, we can check to see that each of the steps occurs at some point in the process.

Integrating Assignments with Course Objectives

Effective writing assignments are carefully integrated with course objectives. Here "effective writing assignments" refers to assignments that facilitate the learning of pertinent discourse and course content knowledge. Although students resent assignments that are or appear to be merely tacked on to a course, they respond much more favorably if they understand how the assignment helps them reach a major course objective.

Our task then as faculty is to step back and review our own course objectives, so we can produce more meaningfully integrated writing assignments. Putting our existing course objectives aside for a moment, we should brainstorm ideas on this first question:

- What should students know and be able to do when they finish my course?

Ideas generated from this prompt can then be compared to existing course objectives, which may stimulate revision. Next we are prepared to explore the following questions:

- Since I last taught this course, should any objectives be eliminated, revised, or grouped with other objectives?
- Do I need to add communications objectives to the list? (e.g., "Students should understand how technical, project, and consulting-style reports function in certain geoscience contexts.")
- In the past, which objectives tended to be most difficult for students to learn? That is, what are the sticking points? Also, which objectives tend to be most pivotal to achieving forthcoming objectives? That is, which objectives scaffold to future objectives?

Once we have explored this terrain, we can examine the mileage issue, or how to achieve L = M. More mileage is gained from assignments that address multiple course objectives (the quantity test), that meet crucial objectives such as sticking points or scaffolded objectives (the quality test), or that pass both tests.

In the following example, three course projects are scaffolded to achieve specific course objectives and address sticking points. The course is "Geological Engineering Site Investigation," taught at the senior undergraduate and graduate level. It covers aspects of investigation for construction, natural hazards, and groundwater, including drilling and sampling methods, materials logging, field testing, and instrumentation. Although the course focuses on geotechnical and hydrogeologic applications, the course objectives noted below could easily be modified to address minerals or petroleum exploration:

A. Evaluate geologic and engineering conditions of land based on field mapping and subsurface data and communicate these evaluations effectively in writing
B. Identify and select appropriate methods of site mapping, drilling, sampling, field testing, and instrumentation
C. Apply geologic concepts to extrapolate limited data into three-dimensional site models
D. Develop students' experience base and judgment skills through exposure to a wide variety of data types and through practice solving real-world problems

After the course had been taught several times, several sticking points were identified:

1. Focusing writing properly (eliminating information that is not important to the "story," improving transitions between ideas, developing a concise narrative, etc.)
2. Justifying opinions and separating them from factual information
3. Selecting appropriate investigation tools

<table>
<thead>
<tr>
<th>Faculty Goal</th>
<th>L=M Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>How can I reduce grading time?</td>
<td>II III III III</td>
</tr>
<tr>
<td>How can I provide the kind of feedback that students are more likely to use in future writing assignments?</td>
<td>n/a II III II</td>
</tr>
<tr>
<td>How can I help students learn the typical sticking points?</td>
<td>III III II III</td>
</tr>
<tr>
<td>How can I help students learn the scaffolded objectives?</td>
<td>III III III II</td>
</tr>
<tr>
<td>How do I get students to analyze, synthesize, and evaluate concepts?</td>
<td>III III II III</td>
</tr>
<tr>
<td>How can I be more consistent and objective in my grading?</td>
<td>n/a III n/a II</td>
</tr>
<tr>
<td>How can I clearly convey assignment expectations?</td>
<td>I III II n/a</td>
</tr>
<tr>
<td>How do I get students to incorporate brand new knowledge into their writing?</td>
<td>II III III II</td>
</tr>
</tbody>
</table>

Table 1. Relative utility of writing-integration strategies for common faculty goals.
4. Critically evaluating their own and others' written work
5. Improving their ability to deal with ambiguous data and match precision levels to project requirements

Table 2 outlines the project assignments and which objectives (lettered) and sticking points (numbered) the assignment is intended to address. Table 2 makes manifest the degree to which a given set of assignments addresses certain learning objectives and sticking points.

In addition to focusing on course-specific issues, the writing assignments also utilize more abstract cognitive skills, as identified by Bloom (1956), and summarized in Table 3. All three projects require students to critique ideas and make judgments among multiple valid solutions, so student participation occurs at high learning levels, including analysis, synthesis, and evaluation, which are the more abstract mental operations in Bloom's Taxonomy. For the Site Investigation course, and likely for most geoscience courses, knowledge is practiced and tested in lecture time and through exams, and application is addressed in weekly labs.

If one of our course objectives is to nudge students from their current level of problem solving ability to a successive level, we should examine how assignments achieve this goal. One helpful guide in assessing such current levels comes from research on problem solving processes, summarized in simplified form in Table 4. This research focuses specifically on how people resolve open-ended dilemmas and develop reflective judgment capabilities (King and Kitchener, 1994; Kitchener and King, 1981). These capabilities involve being able to evaluate multiple aspects of a problem, reach a solution or conclusion, and justify that conclusion with convincing evidence. According to this research, those capabilities are closely related to the stages outlined in Table 4, and learners move through these stages slowly and sequentially (King and King, 1981). Perhaps most striking about the developmental stages is how in each successive stage, learners are better able to tolerate anomaly and ambiguity in data interpretations. At later stages, in fact, anomaly and ambiguity are sought out. Also of interest are the important shifts between stages three

Table 2. Example of use of scaffolded assignments to address multiple course objectives and sticking points.

<table>
<thead>
<tr>
<th>Project</th>
<th>Objective</th>
<th>Sticking Point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Project 1</td>
<td></td>
<td></td>
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<tr>
<td>Writing Skill:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Memorandum</td>
<td></td>
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<tr>
<td>Technical Skill:</td>
<td></td>
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<tr>
<td>Engineering</td>
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<tr>
<td>stratigraphic</td>
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<td></td>
</tr>
<tr>
<td>column</td>
<td></td>
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<tr>
<td>Project 2</td>
<td></td>
<td></td>
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<tr>
<td>Writing Skill:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proposal</td>
<td></td>
<td></td>
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<tr>
<td>Technical Skill:</td>
<td></td>
<td></td>
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<tr>
<td>trench log and</td>
<td></td>
<td></td>
</tr>
<tr>
<td>general site</td>
<td></td>
<td></td>
</tr>
<tr>
<td>map</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing Skill:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work Plan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Skill:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>soils map</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Bloom’s (1954 and 1956) taxonomy of educational objectives described by level of abstraction, from knowledge (least abstract) to evaluation (most abstract).
<table>
<thead>
<tr>
<th>Description of Stage in Reflective Judgment Model</th>
<th>Common Student Responses to Interpreting Anomalies and Ambiguity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knowledge is unchanging, absolute, accessible, and concrete.</td>
<td>One interpretation of the meaning and implications of data must be correct, and all others are incorrect; anomalies and ambiguity result from error and should be corrected.</td>
</tr>
<tr>
<td>2. Knowledge is certain but may not be accessible to all, perhaps only to certain authorities.</td>
<td>One interpretation of the meaning and implications of data must be correct, and authorities should be consulted to correct anomalies or ambiguity.</td>
</tr>
<tr>
<td>3. Knowledge is certain, absolute, may be accessible to anyone, and no rational method for justifying beliefs exists.</td>
<td>One interpretation of the meaning and implications of data must be correct, and sometimes even non-authorities can reconcile anomalies and ambiguity, but not rationally.</td>
</tr>
<tr>
<td>4. Knowledge is uncertain, idiosyncratic, and interpreted subjectively.</td>
<td>Multiple interpretations of the meaning and implications of data may exist, but determining which interpretation is most correct is problematic due to the subjective nature of interpretation.</td>
</tr>
<tr>
<td>5. Knowledge is uncertain and subjective, though interpretable using rules of inquiry.</td>
<td>Multiple subjective interpretations of the meaning and implications of data may exist, and certain rules can help us better understand which may be more valid, though not entirely.</td>
</tr>
<tr>
<td>6. Knowledge is relative and constructed yet justifiable on the basis of rational arguments that involve the comparison of different evidence.</td>
<td>Multiple interpretations of the meaning and implications of data may exist, and the merits of each interpretation can be evaluated by comparing supporting evidence.</td>
</tr>
<tr>
<td>7. Knowledge is relative and constructed, though some interpretations have greater weight when justified probabilistically.</td>
<td>Multiple interpretations of the meaning and implications of data may exist, and some interpretations gain more merit because they are justified with more probable evidence.</td>
</tr>
</tbody>
</table>

Table 4. A summary of King and Kitchener’s stages in the reflective judgment model and common student responses to interpreting anomalies and ambiguity (Adapted from Bruning et al., 1999; King and Kitchener, 1994; Kitchener and King, 1981).

and four in terms of the certainty of knowledge and between stages five and six from uncertain to contextual or relative knowledge. As educators, our task is to determine where our students are at present and examine how our assignments help move their problem solving abilities forward.

**Designing Effective Assignments** - Once we have clearly identified our course objectives, we can design assignments that achieve those objectives, as in the example in Table 2. Typically, effective assignments are designed and redesigned, honed through trial and error, student feedback, new research, and our own observations. However, as described below, effective assignments contain stable and clearly identifiable components (for more information, see Colorado School of Mines, 2004; Gottschalk and Hjortshoj, 2004; Kovac and Sherwood, 2001).

- **How the assignment helps achieve certain course objectives** should be stipulated so students see the overarching purpose; that is, how the part relates to the whole. If we are guided by the notion that L = M, students will benefit from assignments that help achieve multiple objectives or that focus on key sticking points or scaffolded objectives.

- **Our audience** is clearly stipulated. This tells students to whom they are writing, and may include specific audience characteristics such as position within an organization (real or hypothetical), power relationships, local or corporate culture issues, knowledge level of the subject, perspective toward a subject, and, if relevant, education, age, ethnicity, gender, religion, or political affiliation.

- Students are able to articulate the assignment's purpose. One of the authors has more than a decade of experience working in writing centers and has heard countless students balk when asked to describe the purpose of a paper. Students struggle less and produce better work when they write with a clear sense of their intention. To attempt to minimize the gap between student and faculty perceptions of assignment intentions, faculty should identify the key verb(s) that describe the assignment purpose, as well as the level of abstraction according to Bloom. The verbs listed in Table 3 represent only a small sample of potential assignment purposes. Regardless of their nature, assignment purposes should foster growth from students' current cognitive and problem solving ability levels to successive levels, as noted above (King and Kitchener, 1994; Kitchener and King, 1981).

- Effective assignments often stipulate the context in which the writing is situated. Contextual information is vital because effective writers relate ideas to surrounding social, cultural, or other contextual realities. For example, a hydrogeologic consulting report will likely be written differently if the client has recently received negative media exposure for contamination problems at another site. Reports on geologic hazards may take a different approach after significant seismic activity in a given location than if no such activity had occurred. Although the facts presented should not change for obvious ethical reasons, the way in which those facts are presented could change. Real writing occurs not in a vacuum but in complex contexts.

- **Tips** for completing the writing and thinking processes involved may be suggested. For example, less experienced writers may assume that they must write
scientific report sections in the same order in which those sections appear to readers—abstract, introduction, methods, results, and discussion. However, more experienced writers know that it may be easier to write the sections in a different order, depending on thinking and experimental processes.

• **We should include the grading criteria.** When students know concretely what constitutes an upper, middle, and lower range written performance—ideally via examples of previous, anonymous student work—they are in a much better position to meet our objectives. Instructor comments on such written performances are quite helpful in conveying expectations. A rubric can also convey this range of performances, as explained below. The combination of a rubric with a range of annotated examples is ideal in making the grading criteria concrete.

• **Finally, we should clarify assignment details** such as length, any preferred documentation and organizational formats, due date, and the number, type, and variety of sources, if applicable.

Rubrics are descriptive scoring schemes that have several advantages for both students and faculty (Moskal, 2000; Moskal and Leydens, 2000). Generally, scoring rubrics for most geoscience writing assignments should recognize the importance of writing mechanics; persuasion using scientific evidence; the value of figures, diagrams, and tables; and geology-specific elements such as maps, investigation plans, and resource analyses. By using scoring rubrics on large writing assignments, such as projects, consulting-style reports, and reports on technical topics, as in Table 5, faculty can accrue several benefits. The act of writing the rubric clarifies our assignment expectations in our own mind and forces us to make implicit criteria more explicit. Finally, grading of the assignment is streamlined and rendered more efficient because we have a consistent mechanism to track progress and quickly and more objectively evaluate the quality of the document. Well-designed rubrics augment the validity and reliability of scores of student performance (see Moskal and Leydens, 2000).

Also, students benefit by seeing performance expectations clearly conveyed via rubrics. During the drafting phase, students can go through the valuable experience of revising their own or each other’s work (for more on peer review, see the books by Gottschalk and Hjortshøj, 2004; Kovac and Sherwood, 2001). Rubrics may also provide more usable feedback to students. Finally, a more efficient grading process means students will receive feedback prior to the next assignment. As Table 5 shows, rubrics have several common features, such as performance levels (in this case, from novice to exemplary), categories of objectives (e.g., persuasive writing, figures and tables, etc.), and descriptions of performance criteria, such as those seen under each of the performance level columns.

In addition to the report rubric, we have also included a rubric on derivative maps in Table 6. Some types of geologic mapping include a substantial writing

<table>
<thead>
<tr>
<th>Objectives</th>
<th>1 - Exemplary</th>
<th>2 - Proficient</th>
<th>3 - Apprentice</th>
<th>4 - Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Format / layout / organization</td>
<td>Report tells a very clear, coherent story with excellent transitions</td>
<td>Report is clear and tells a coherent story, strong throughout</td>
<td>Report has some gaps in story, some weak sections</td>
<td>Report is poorly organized, missing key sections</td>
</tr>
<tr>
<td>Writing mechanics</td>
<td>Report is virtually error-free, and contains few if any reader distractions</td>
<td>Report is logical and easy to read, and may contain a few errors causing minimal reader distraction</td>
<td>Report is generally clear, but distracting errors and flow make it difficult to follow at times</td>
<td>Report contains many distracting mistakes, making it generally difficult to follow</td>
</tr>
<tr>
<td>Persuasive writing</td>
<td>Every idea or conclusion is logically supported by relevant facts, and includes judgment of the reliability of data</td>
<td>Every idea or conclusion is logically supported by relevant facts</td>
<td>Relates ideas and conclusions to facts or concepts taught as fact</td>
<td>Opinion and fact not clearly separated. Basis for opinions is unclear at times</td>
</tr>
<tr>
<td>Figures / Tables</td>
<td>All figures and tables are easy to understand, and are clearly linked to the text. Story can be told almost entirely through figures.</td>
<td>All figures and tables can be understood with information given and are linked to text. One or more need improvement. May need more figures to tell the story.</td>
<td>Figures and/or tables are hard to understand, are not all linked to text. Several need improvement. Several more figures are needed to tell the story.</td>
<td>Figures are hard to understand, and are not adequate to advance the story. Tables are not useable as presented.</td>
</tr>
<tr>
<td>References</td>
<td>All sources identified and referenced appropriately. Evidence of careful and thorough research for outside information.</td>
<td>All sources identified and referenced appropriately. Includes mostly readily available works.</td>
<td>All sources identified. Only readily-available works included. Some weaknesses in referencing, such as missing publisher information.</td>
<td>Sources not identified, not sufficiently thorough, not referenced properly, or not used.</td>
</tr>
<tr>
<td>Typical Grade (average):</td>
<td>92-95 (93)</td>
<td>87-91 (90)</td>
<td>83-86 (84)</td>
<td>76-82 (78)</td>
</tr>
</tbody>
</table>

Table 5. Scoring rubric for projects, consulting-style reports, and reports on technical topics.
Incorporating Writing to Learn (Process Writing)

Some effective writing assignments may never have to be graded, though that may seem odd at first. A distinction should be made between assignments that have as their objective writing to communicate versus writing to learn. The more product-oriented writing-to-communicate activities focus on writing as a tool for communicating what students already know; by contrast and by complement, write-to-learn activities seek to facilitate discovery of what students know, know partially, and do not know but need to learn (Gottschalk and Hjortshøj, 2004; McLeod and Miraglia, 2001; Young, 1999). Write-to-learn activities are also called process activities because they are often used to unearth knowledge and knowledge gaps as a means to another end: namely, a writing-to-communicate activity. This complementarity is illustrated below.

An example of process writing to be used in conjunction with a writing assignment for Structural Geology is shown in Figure 1, and an example for a geologic hazards report is shown in Figure 2. In both cases, short, non-graded exercises will help students focus their thinking, prepare for the next stage of their report, and concentrate on potential sticking points or scaffolded objectives (such as separating fact from opinion or reconciling conflicting information). These types of process writing activities can occur in class and often serve as catalysts for discussions that reveal knowledge gaps, so students are encouraged to save their process writing to facilitate conceptual-level revisions of their reports.

In sum, process writing has several advantages, including that it

- Objectifies and makes more concrete ill-formed and emerging ideas
- Reinforces the habit of transforming complex ideas into words on paper
- Provides an opportunity to write to learn, as opposed to writing to communicate, so students see writing as a vehicle for discovery
- Fosters metacognition and thus discovery about one's problem-solving processes
- Allows faculty members a window into students' reasoning processes

Table 6. Scoring rubric for derivative maps.

<table>
<thead>
<tr>
<th>Objective</th>
<th>1 - Exemplary</th>
<th>2 - Proficient</th>
<th>3 - Apprentice</th>
<th>4 - Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoroughness of hazard identification</td>
<td>Carefully discusses all hazards. Includes obvious references to information from lectures.</td>
<td>Complete list of hazards</td>
<td>Includes the major hazards affecting the area</td>
<td>Contains only some of the major hazards</td>
</tr>
<tr>
<td>Clarity of hazard level distinction</td>
<td>Includes a clear description of the characteristics of each hazard level, with obvious, careful thought into the divisions</td>
<td>Includes a clear description of the characteristics of each hazard level, based on observable or measurable traits</td>
<td>Hazard level descriptions are vague or based on non-measurable or non-repeatable parameters</td>
<td>Unclear or insufficient rationale for hazard levels, or hazard levels are not clearly distinguished</td>
</tr>
<tr>
<td>Map preparation skills</td>
<td>Map is neat, professional in appearance, with carefully drawn divisions between units, with attention to subdivisions within geologic or soils units</td>
<td>Map is neat, professional in appearance, with carefully drawn divisions between units. Divisions are mostly accurate.</td>
<td>Map is neat, but may contain some vague contacts between units</td>
<td>Map is rough-draft quality, with vague contacts between units</td>
</tr>
<tr>
<td>Mitigation Methods</td>
<td>Described in detail and carefully matched to each hazard level. No overuse of &quot;avoidance&quot; methods.</td>
<td>Methods are matched to each hazard level, and report demonstrates critical analysis of use of each method</td>
<td>Report demonstrates attempt to match methods to hazard level</td>
<td>Methods listed as a block, simply restated from lecture</td>
</tr>
<tr>
<td>Report presentation and writing</td>
<td>Report is virtually error-free, logical, easy to read</td>
<td>Report is logical and easy to read, may contain a few errors</td>
<td>Report is generally clear, but errors, flow, and logic make it difficult to follow at times</td>
<td>Report is poorly organized, contains many mistakes, and is difficult to follow</td>
</tr>
</tbody>
</table>

Typical Grade (average):

- 92-95 (93)
- 87-91 (90)
- 83-86 (84)
- 76-82 (78)
Fosters critical thinking skills as scaffolds to future written products or to address sticking points, allowing students to fill in crucial conceptual pieces of a larger puzzle.

Can be used as a short, productive break in a lecture.

Does not have to be graded.

However, students may perceive process writing as busywork—and rightly so—if it is not thoughtfully integrated with and explicitly linked to course objectives and to the more formal assignments that foster WID.

Evaluating Writing Effectively and Efficiently - Many faculty begin their grading careers with good intentions, marking every error or commenting extensively on student papers, and quickly burning out because of the time and frustration involved. But there is a better way. Effective and efficient graders adhere to some key concepts:

1. As a rule of thumb, include a summary comment with no more than two or three strengths and two or three areas for improvement (Gottschalk and Hjortshoj, 2004; Kovac and Sherwood, 2001). Noting every strength or weakness on student papers is

### Table 7. Scoring rubric for essays.

<table>
<thead>
<tr>
<th>Objective</th>
<th>1 - Exemplary</th>
<th>2 - Proficient</th>
<th>3 - Apprentice</th>
<th>4 - Novice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recollection of facts</td>
<td>Touches on every important fact related to the topic</td>
<td>Covers the critical facts related to the topic</td>
<td>Covers a majority of facts related to the topic</td>
<td>Contains only some of the obvious facts</td>
</tr>
<tr>
<td>Demonstrated understanding</td>
<td>Original wording, analogies, or examples. Applies taught concepts to answer the question.</td>
<td>Steps beyond simple recall and attempts to interpret ideas to better answer the question</td>
<td>Recalls appropriate concepts or examples to address question</td>
<td>Apparent misconception(s) or knowledge gap(s)</td>
</tr>
<tr>
<td>Linking of topics</td>
<td>Carefully evaluates multiple topics that apply to the question, and synthesizes them into a coherent answer</td>
<td>Incorporates multiple concepts to answer the question and demonstrates judgment in applicability of concepts</td>
<td>Answers the question using several concepts or topics</td>
<td>Answers the question using a single concept or topic</td>
</tr>
<tr>
<td>Persuasive writing</td>
<td>Every idea or conclusion is logically supported by relevant facts. Includes judgment of reliability of data.</td>
<td>Every idea or conclusion is logically supported by relevant facts</td>
<td>Relates ideas and conclusions to facts or concepts taught as fact</td>
<td>Opinion and fact not clearly separated. Basis for opinions is unclear at times</td>
</tr>
</tbody>
</table>

Typical Grade (average):

| 92-95 (93) | 87-91 (90) | 83-86 (84) | 76-82 (78) |

### Table 8. Scoring rubrick for lab reports.

- Fosters critical thinking skills as scaffolds to future written products or to address sticking points, allowing students to fill in crucial conceptual pieces of a larger puzzle.
- Can be used as a short, productive break in a lecture.
- Does not have to be graded.

However, students may perceive process writing as busywork—and rightly so—if it is not thoughtfully integrated with and explicitly linked to course objectives and to the more formal assignments that foster WID.

Evaluating Writing Effectively and Efficiently - Many faculty begin their grading careers with good intentions, marking every error or commenting extensively on student papers, and quickly burning out because of the time and frustration involved. But there is a better way. Effective and efficient graders adhere to some key concepts:

1. As a rule of thumb, include a summary comment with no more than two or three strengths and two or three areas for improvement (Gottschalk and Hjortshoj, 2004; Kovac and Sherwood, 2001). Noting every strength or weakness on student papers is

Typical Grade (average):

| 92-95 (93) | 87-91 (90) | 83-86 (84) | 76-82 (78) |
counterproductive for faculty and students. Faculty risk burnout, and students are overwhelmed with more information than they can usefully transfer to future writing occasions. Although writing skills atrophy fairly quickly through disuse, they also develop slowly over time (Lindemann, 1995). A violinist, skier, or writer does not need to hear about all of the errors in his or her performance but about the most salient ones that will lead to the greatest improvement. And although it may seem inefficient to comment on strengths, doing so sincerely builds confidence and ensures that students do not in their revision process eliminate aspects of their writing that are working well. Most important in a summary comment is to address what students want to hear most: whether the paper addressed readers’ expectations and the degree to which readers understood the ideas the writer was trying to convey. Research indicates that students greatly value thoughtful feedback, even on exemplary essays (Gottschalk and Hjortshøj, 2004). Also, we should avoid an exasperated tone and comments on students’ character or work habits, separating the student from the written performance (Gottschalk and Hjortshøj, 2004).

2. Focus on global issues, not minutia (Gottschalk and Hjortshøj, 2004; Kovac and Sherwood, 2001; Moss

Figure 1. Report on the structural geology of an area.

Figure 2. Report on geologic hazards of an area.
and Holder, 1988). Since faculty cannot rectify every competence and performance weakness in student writing in the long run, we need to focus on a few global issues. What constitutes a global issue versus minuita will vary from assignment to assignment. Sometimes a minute issue becomes global because it recurs frequently and significantly distracts readers from understanding the content. Only a few instances of recurring issues need be marked, along with encouragement to identify and address other instances. Also, as a rule of thumb, incorrect grammar should only be marked when it disrupts readers’ understanding of the content (Moss and Holder, 1988). One need not be a grammar expert to provide useful feedback regarding grammar; brief marginal comments indicating that a reader became confused by a sentence or passage are sufficient (e.g., "this passage is difficult to follow. Clarity"). Generally, students can correct such errors on their own.

3. Marginal comments should be brief, few, and should substantiate the summary comment (Gottschalk and Hjortshøj, 2004). For example, if a summary comment tells a student that certain knowledge claims were insufficiently supported with data, marginal comments should pinpoint specific instances of insufficient support. To save time, some instructors use marginal shorthand or symbols; for example, we might in a summary comment tell students that instances of insufficient evidence are marked with an asterisk in the margins. Generally, because students tend to pay more attention to summary comments (Kovac and Sherwood, 2001), marginal comments should be used sparingly.

4. Communicate your expectations and stick to them (Gottschalk and Hjortshøj, 2004). Conveying assignment expectations via rubrics or other means narrows the gap between our expectations and their understanding of the assignment, increasing chances of better performances.

5. Use rubrics to increase efficiency (Moskal, 2000; Moskal and Leydens, 2000). Writing the same comment on a paper three or four times is inefficient, so recurring issues can be highlighted on the rubric before being returned to students. A number of other evaluating alternatives exist. For example, rubrics can contain a space for the instructor to write a summary comment and can contain check marks in each performance criteria description box to avoid highlighting. Rubrics are generally used either analytically or holistically; analytic use involves attributing a point value to each performance criterion while holistic use involves attributing a single point value to the overall performance. Each method has advantages and disadvantages. For instance, the analytic method allows instructors to weigh certain performance criteria more heavily than others, yet the same method assumes performance criteria are discrete rather than overlapping, a problematic assumption (Gottschalk and Hjortshøj, 2004; Kovac and Sherwood, 2001). In a rubric such as the one in Table 5, problems with organization may spill over into a paper’s persuasive potential, and an analytic approach would cause a student to lose points in two places for a single issue. Whichever method we select, rubrics can serve as an opportunity to revise assignments for future semesters as we discover recurring problems or assignment expectations that are clear in our minds but not stated explicitly on the rubric.

Consulting Campus Resources - Most college campuses have writing faculty with a background in WID and/or WAC, and these colleagues can be helpful in working with faculty across disciplines as we (re)design our syllabi to meaningfully integrate writing. Also, campus writing center tutors provide one-to-one instruction that is tailored to individual writers’ learning needs, so we can include campus writing center hours, location, and contact information on our syllabi.

The L = M concept functions best when we integrate writing in our courses in light of logistical realities such as class size, class level (sophomore, senior, graduate students, etc.), and class type (field, lab, lecture/lab). Finally, we should also consider our own work load, teaching style, and our students’ learning styles.

ASSESSMENT OF L=M STRATEGIES

Using the strategies described in this paper, the authors are currently conducting longitudinal research on the role of writing in a geoscience course.

Initial feedback of student perception of L=M techniques is available from a written evaluation completed in the spring of 2005 in the Geological Engineering Site Investigation course mentioned above. In their opinion, process writing helped students to "clarify and focus their thoughts" and rubrics made assignment expectations "very clear." Students unanimously agreed that the quality of written feedback on their assignments was better than that received in other classes, even though the quantity of feedback was sometimes more and sometimes less. When asked how this feedback might change their future writing, many students expected that they would focus on the various issues identified by the instructor as sticking points for the course. We view this recognition as a success: students have become convinced that sticking point issues are important and require extra attention on their part.

Overall grades on a written term project improved an average of four points on a 100-point scale from 2004 (n=13), when no specialized writing instruction techniques were used, to 2005 (n=8), when several of the techniques in this paper were used; the median grade improved by three points from 2004 to 2005. Improvements were also seen when comparing 2005 grades to 2002 (n=10) and 2003 (n=10).

CONCLUSION

In this paper, we have described strategies that we think will foster greater learning of geoscience content. Integrating writing by using the five strategies described above may take more time initially, but in our experience that initial time investment is worthwhile because of the long-term benefits: it yields a better final written product and higher levels of student and faculty satisfaction with the overall teaching and learning experience. Further, once written, materials such as writing assignments, rubrics, and process writing prompts generally need
only be revised as we learn from our students over time. In sum, \( L = M \) allows us to

- Achieve more learning by testing assignments for quantity and quality, focusing assignments so they facilitate learning of the most difficult and crucial objectives.
- Spend less time grading yet achieve more learning by thoughtfully integrating scaffolded process writing assignments at crucial junctures in the course.
- Grade less and achieve more learning and better writing by developing rubrics that clarify our expectations up front and facilitate revising and grading processes.
- Provide more consistent and objective evaluative feedback, which students can apply to future writing situations.
- Foster more abstract levels of thinking and stronger problem-solving abilities.

The strategies described here are among many factors that mitigate and facilitate learning. Other factors center on the institutional and classroom climate and the students' background, including but not limited to culture, prior knowledge, communicative competencies, as well as learning goals, values, aptitudes, and styles. Of the many factors, the way we integrate writing is among those factors most in our control.

Finally, any claim about writing and learning should be qualified with an important caveat: writing does not belong in all courses. In fact, some research suggests that writing is not particularly useful in facilitating learning that primarily involve knowledge and comprehension; by contrast, writing is a stronger learning tool in courses involving more abstract and open-ended mental operations such as analysis, synthesis, and evaluation (for a summary of this research, see Ackerman, 1995). It is entirely possible that more harm than good can emerge from forcing writing into certain courses, especially because students could rightly see writing not as a tool for learning, but one that wastes time that could be more productively spent activating other learning tools.

**ACKNOWLEDGMENTS**

Thanks go to the dozens of engineering and applied science faculty who have participated in and helped to fine tune summer WAC/WID workshops over the past several summers. Nigel Middleton, Executive Vice-President for Academic Affairs and Dean of Faculty at the Colorado School of Mines, also deserves recognition for consistently funding stipends for faculty to participate in these workshops.

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