CHAPTER 8.

WRITING TO LEARN AND THINK CRITICALLY IN STEM: ENGAGING STUDENTS IN DISCIPLINARY KNOWLEDGE AND PRACTICES

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> Many claims have been made in the past four decades about the efficacy of writing as a means of fostering student learning in a variety of disciplines. Yet, reviews and meta-analyses of publications about the implementation of writing-to-learn (WTL) pedagogies show mixed results.
>
> – Anne Ruggles Gere et al. ("A Tale of Two Prompts")

The use of writing as an aid to learning has long been recognized as an effective educational practice (see, for example, Kuh's 2008 discussion of writing in the disciplines as a high-impact practice). I'm tempted to think that it was among the earliest uses of writing, following only its uses in record keeping, naming, law, and religion (Clayton). It supports remembering knowledge, developing and demonstrating understanding, reflecting on what has been learned, and engaging in analysis, synthesis, and evaluation. Writing activities and assignments, as a result, have served as an enduring aspect of education in general and of higher education in particular.

Yet we seem to find it difficult to talk with precision about the roles writing serves and the forms it takes in higher education. We treat it in much the same way we treat concepts such as creativity, critical thinking, and engagement—as something that is widely understood even when it is abundantly clear that we mean quite different things when we talk about it. Consider the wealth of terms we use to describe writing in higher education: *writing across the curriculum (WAC)*, *writing in the disciplines (WID)*, *writing to learn*, *learning to write*, and *writing to communicate* come immediately to mind. And there are others, such as *writing to demonstrate learning*, a term used widely in secondary education, and the evocative *writing to think*.

There are advantages to this wealth of terminology—this "big tent," so to speak. That said, a lack of precise terminology—and, perhaps more important,

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divergent understandings of how we might use writing to support our work as educators—can lead to misunderstandings about our curricular goals and a consequent lack of effectiveness in our instructional practices.

For several years, I've focused on what I see as an overly broad definition of a key concept within the WAC movement: writing to learn (see "A Middle Way," "WAC and Critical Thinking"). In common practice, it includes such diverse activities as

- listing key ideas in a reading assignment or class discussion,
- summarizing and responding to readings,
- reflecting on personal and professional connections to course concepts,
- applying disciplinary interpretive frameworks to a text or video,
- analyzing texts and other forms of media, and
- evaluating the strengths and weaknesses of competing claims or approaches.

These are all important and productive assignments. They help students learn. And they hold significant advantages over activities such as cramming for a quiz or an exam.

Yet they exhibit marked differences from one another. Consider the critical thinking skills, for example, required to jot down three questions about an assigned reading at the beginning of an economics class meeting and those required to apply a Keynesian analysis of claims made in a presidential debate. Consider as well where they fall along a spectrum from low-stakes to high-stakes writing tasks (Elbow) and from writer-based to reader-based prose (Flower). Finally, consider how they might vary in their meaningfulness for the students who work on them (see work by Eodice et al.).

Unfortunately, in disciplines outside writing studies the concept of writing to learn is understood broadly as anything that is not geared toward helping students prepare for communication in their disciplines or professions. In other words, it's everything except writing in the disciplines. In this sense, expressing a desire to use writing-to-learn tasks in a course is much like saying you want students to develop critical thinking skills. It's a laudable goal, but it lacks the specificity that is an essential characteristic of assignments that are well-aligned with course goals.

I've argued elsewhere about the value of distinguishing between writing-to-learn activities that focus largely on remembering, understanding, and reflecting and writing-to-engage activities that involve applying, analyzing, and evaluating ("Middle Way"). This focus on critical thinking supports alignment between the curricular goals of a course and instructor expectations about the kinds of work they assign. It also calls instructor attention to the

development of the general and disciplinary critical thinking skills students encounter as they progress from lower-division to upper-division courses. Distinguishing between writing to learn and writing to engage can contribute in useful ways to student learning and to their preparation for further work in their disciplines. In this chapter, I extend that argument by exploring how complex writing-to-engage tasks in the STEM disciplines can move beyond writing-to-learn activities into assignments that begin to engage students in writing in the disciplines.

WRITING TO LEARN AND WRITING TO ENGAGE AS CONTIGUOUS AND OVERLAPPING ACTIVITIES

Within the STEM disciplines, educators have made extensive use of writing to support student learning. Two major research projects led respectively by Anne Ruggles Gere and Meena Balgopal that have resulted in several publications, for example, have advanced our understanding of the use of writing tasks in STEM courses. In this volume, for example, Ginger Shultz and her collaborators Amber J. Dood and Solaire A. Finkenstaedt-Quinn—who have worked closely with Gere—report on a study of students' perceptions of how writing shaped their learning in chemistry courses at the University of Michigan (see Chapter 9). And while these projects are noteworthy, they are far from alone. Searches of databases for the phrase *writing to learn* in the STEM disciplines produce hundreds of results (e.g., Graham et al.).

Certainly, the writing activities and assignments described in these studies vary widely in the stakes and meaningfulness they hold for students as well as in their cognitive complexity. But they also, as a group, show learning gains associated with the use of writing. By considering the characteristics of successful writing activities and assignments in light of the course in which they are assigned, the students in the course, and the goals of the course, we can make progress on identifying writing activities and assignments that are well aligned with curricular goals. Developing a classification scheme based on this information would support decisions regarding when to assign writing in a given course, what type of writing activity to assign, and how to support students as they work on their writing.

My attempts to create such a scheme have involved aligning typical writing assignments with the taxonomy of educational objectives in the cognitive domain developed by Benjamin Bloom and his colleagues in the 1950s and later modified by Loren W. Anderson and David R. Krathwohl in the early 2000s. I've modified it further to include a key critical thinking activity that is treated implicitly in Bloom's taxonomy: reflecting.

Figure 8.1. Bloom's taxonomy as modified by Anderson and Krathwohl and modified further to add reflecting as a distinct cognitive skill.

Using this modified version of Bloom's taxonomy, I've proposed a spectrum of writing activities and assignments ranging from low-stakes, writer-based writing-to-learn activities to highly rhetorical, high-stakes, genre-informed, and reader-based writing-in-the-disciplines activities. Between the ends of the spectrum, I've placed a new category of writing-to-engage activities which align with Bloom's higher-order thinking skills but do not necessarily share the characteristics of genres that commonly circulate within publication venues in a disciplinary or professional community.

This spectrum is not offered as an argument that we've been getting the "writing to learn" discussion wrong all along but rather to suggest that we can benefit from greater precision in discussing the impact of assignments that have quite distinct characteristics. Much of this thinking emerged from my experiences working as the director of a teaching and learning center. My efforts to introduce writing tasks as a key part of a large, five-year course-redesign initiative helped me recognize the need for more nuanced distinctions among the various writing activities that could be used to accomplish course goals. It was also shaped by conversations with colleagues including Terry Zawacki, Marty Townsend, Susan McLeod, Linda Adler-Kassner, Justin Rademaekers, and Chris Anson, as well as numerous publications that address the relationship between writing and critical thinking (see, for example, McLeod and Elaine Maimon's work in this area). Over time, I began to differentiate activities that focused primarily on gaining an understanding of course concepts and processes and those that engaged students in using those course concepts and processes to accomplish particular goals.

With this in mind, I have attempted to tease out the distinctions among writing to learn, writing to engage, and writing in the disciplines (see Table 8.1).

Figure 8.2. WAC activities and assignments are aligned along a spectrum of critical thinking skills.

Table 8.1. Approaches to WAC

Writing to Learn (WTL)	**Writing to Engage (WTE)**	**Writing in the Disciplines (WID)**
Using writing to help students remember, understand, and reflect on course concepts, conceptual frameworks, skills, and processes.	Using writing to help students assess and work with course concepts, conceptual frameworks, skills, and processes.	Using writing to help students learn how to contribute to discourse within a discipline or profession.
Best characterized as "low-stakes" writing: • The focus is on content; recognizing that students often struggle with new ideas, little or no attention is given to form. • Limited feedback, if any, is provided by the instructor.	Can be characterized as either "low-stakes" or "high-stakes" writing, or it might fall somewhere between the two. Writing to engage assignments can: • Build on WTL activities and assignments. • Support a higher level of engagement with disciplinary concepts and processes than WTL activities and assignments. • Focus on reflecting, applying, and analyzing and might include some attention to evaluating.	Best characterized as "high-stakes" writing: • A greater investment of instructor time is required for designing and responding to student writing. • There is greater potential for student academic misconduct, especially among students who lack confidence in producing original work.
Typical activities include: • In-class responses to prompts • Reflections • Summary/response • Forum discussions • Definitions and descriptions	Typical activities include: • Application of frameworks to texts, media, and cases • Evaluations of alternative approaches and methods • Reflections, critiques, and comparisons • Topic proposals, progress reports, and other brief reports	Typical activities include: • Articles and essays • Presentations • Longer reports • Poster sessions

WRITING TO LEARN AND WRITING TO ENGAGE IN THE STEM DISCIPLINES

While other disciplines have explored the use of writing tasks that align well with the concept of writing to engage, STEM educators have made significant progress in this area. For example, a series of studies conducted by Gere and her colleagues across several STEM disciplines employed a promising assignment-design framework that

- provides a well-defined purpose and audience,
- directs students to work within common and reasonably well-understood genres,
- provides clear indications of the kind of critical thinking required to complete the work,
- requires students to carry out peer review of classmates' work in progress, and
- allows time for reflection on the feedback provided through peer review.

These assignments are described in detail in articles published by teams of scholars led variously by Gere, Finkenstaedt-Quinn, Trisha Gupte, Audrey Halim, Alena Moon, Michael Petterson, Shultz, Robert J. Thompson, Jr., and Field M. Watts.

While these assignments vary from summaries and essays to memos, email messages, and articles, they share a focus on working in substantive ways to understand, reflect upon, and engage critically with the information, ideas, and processes typical of specific STEM disciplines. Their assignment designs range from fairly straightforward directions to write "a summary of how Lewis proposed to simplify the depiction of electron sharing and valence in covalent bonds" (Shultz and Gere 1326)[1] to more complex tasks such as taking on the role of "a volunteer in a social service program who needed to explain the implications of recycling on polymer structure to their supervisor, who hopes to convince donors that recycled plastic can be used to make backpacks for impoverished school children" (Finkenstaedt-Quinn et al., "Investigating" 1611).

These assignments, according to the teams of researchers led variously by Gere, Finkenstaedt-Quinn, Gupte, Halim, Moon, Petterson, Shultz, Thompson, and Watts, draw on three key assignment features derived from a meta-analysis conducted by Paul Anderson and his colleagues of effective writing-to-learn activities and assignments: interactive writing processes, clear expectations, and meaning-making

1 Shultz and Gere note that "Lewis dot structures form the basis of the symbolic language that is used for communication among chemists" (1325). The task they ask students to complete is based on Gilbert Lewis' 1916 article "The Atom and the Molecule," available at https://pubs.acs.org/doi/10.1021/ja02261a002.

activities. A 2019 review of several of these published reports (Thompson et al.) found that these features, in combination with the metacognitive reflection identified in a 2004 meta-analysis by Robert Bangert-Drowns and his colleagues, produced evidence of conceptual learning. For the studies addressed by the Gere, Finkenstaedt-Quinn, Gupte, Halim, Moon, Petterson, Shultz, Thompson, and Watts teams, metacognitive reflection is typically fostered through the use of peer review of initial drafts using tools such as MWrite in combination with subsequent revision (see a description of MWrite in Finkenstaedt-Quinn et al., "Praxis," and its relationship to work conducted by Shultz and Gere in "Writing-to-Learn").

Some of the writing assignments discussed in the studies reported by the Gere, Finkenstaedt-Quinn, Gupte, Halim, Moon, Petterson, Shultz, Thompson, and Watts research teams might fall into the overlap between writing to learn and writing to engage. This is particularly true of assignments that focus primarily on summarizing. The addition of the reflection associated with peer review as well as the higher stakes associated with grading suggests, however, that most of the assignments reported on in these studies require cognitive skills that are more commonly associated with writing to engage, such as application, analysis, and evaluation. Requirements such as the following certainly suggest a high level of engagement with course content and processes:

> Write a memo to the trainer explaining what the statistics show and make an argument for or against inclusion of dark chocolate in the athletes' diet. Your memo should include a discussion of how crossover design affects the data analysis, statistical significance, and what the *p* values indicate about the results, and explain the difference between the meaning of a confidence interval versus confidence level. (Finkenstaedt-Quinn et al., "Utilizing" 370)

This assignment begins with summary, but it also requires application of skills and knowledge gained through the course, analysis of evidence, and the development of an argument for a specific audience. This kind of assignment goes well beyond those that would fit comfortably within the definition of writing to learn found in Table 8.1.

An analysis of the assignments reported in the work by the Gere, Finkenstaedt-Quinn, Gupte, Halim, Moon, Petterson, Shultz, Thompson, and Watts research groups suggests that most of the assignments are consistent with the concept of writing to engage. Each requires students to carry out reflection, application, analysis, and/or evaluation. They often rely on providing a set of recommendations or conclusions. And they sometimes explicitly ask writers to develop an argument. The annotated assignments found in Figures 8.3 and 8.4 illustrate the ways in

which these activities are integrated into the assignments. They also show how purpose, audience, role, and genre play central roles in the assignments.

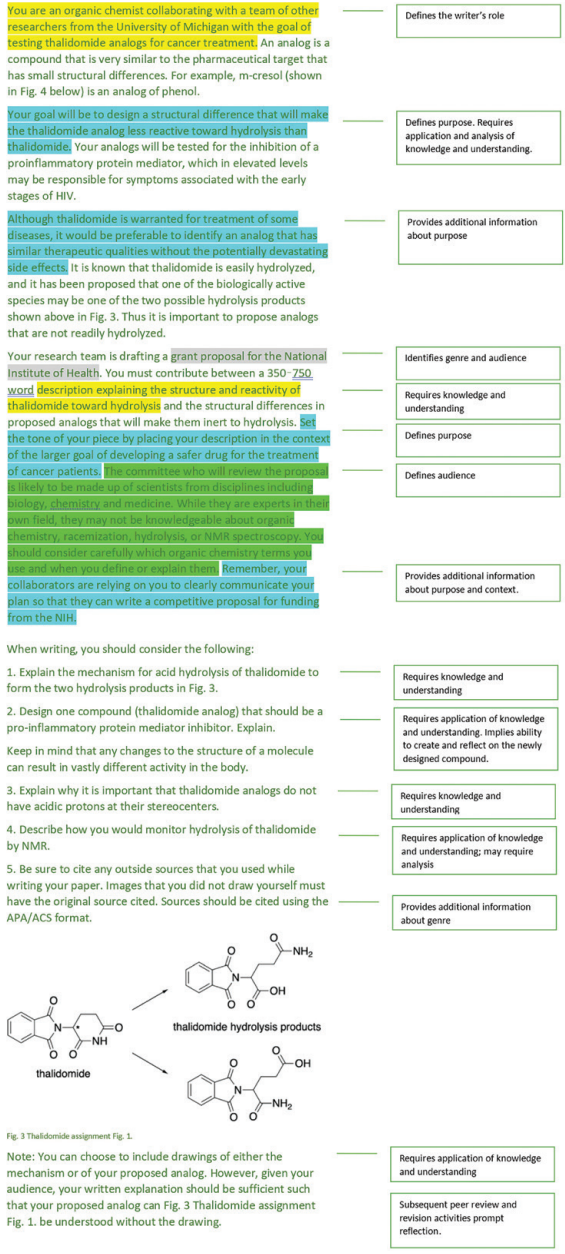

Figure 8.3. Annotated assignment for an organic chemistry course. Source: Gupte et al. 409.

Figure 8.3 shows how the assignment provides guidance in three areas. First, it focuses attention on the rhetorical situation, providing information about the writers' purpose, audience, role, and genre. Second, it provides guidance (not shown in this figure, but available in the full article) on carrying out peer review and engaging in reflection about how the students have given and received feedback and how they might approach the revision of their draft. Finally, it provides strong cues about the type of critical thinking that should contribute to the drafting and revision of their assignment. Building on their knowledge and understanding of course content, students are asked to engage in application as they design a thalidomide analog that will be a pro-inflammatory protein mediator inhibitor (an example of creating, in Bloom's taxonomy). They are also asked to explain how they would monitor the effects of the newly designed thalidomide analog, an activity that would likely involve reflection and analysis.

The work writers carry out to complete this assignment will involve considerations of both their rhetorical situation (developing a key section in an NIH grant proposal) and the content they hope to convey to their readers. The interaction between these two considerations has been termed a process of knowledge transformation (Scardamalia and Bereiter, "A Brief History," "Knowledge Telling"), a key step in conveying complex information to a specific audience. Since the student writers are likely to have little familiarity with the NIH review process, they will almost certainly find it challenging to determine how best to present the findings from their work for inclusion in the grant proposal. In essence, even if they possess a deep understanding of the nature and characteristics of the thalidomide analog they design, they will need to think deeply about how to present that information to their readers.

This process illustrates the overlap between writing to engage and writing in the disciplines. While WID assignments more often focus on an established genre (for example, students might be asked to "write an article reporting the results of your lab experiment for the journal …") and clearly define audience and purpose, complex writing-to-engage activities such as the assignment from Gupte and her colleagues occupy the space between documents such as essays and reports and documents such as conference proposals and journal articles. In this case, students are writing content for a grant proposal, an activity that not only engages them in critical thinking about course content but also exposes them to specific genre conventions. As such, this assignment—like many of the others in the studies conducted by the Gere, Finkenstaedt-Quinn, Gupte, Halim, Moon, Petterson, Shultz, Thompson, and Watts research groups—falls into the overlapping space between writing to engage and writing in the disciplines.

In this way, the rhetorical and cognitive tasks required by the assignment described by Gupte and her colleagues differ in important ways from a typical

writing-to-learn assignment. It requires the writers to engage in most of the cognitive skills in Bloom's taxonomy, and it requires extensive work by students in adapting their knowledge for a specific rhetorical situation. It is a high-stakes (that is, graded) activity. And, since it involves peer review and revision, it goes well beyond the requirements of a single-draft writing-to-learn activity such as developing lists, summarizing a source, or responding to a source. Finally, depending on the writer's interest in the course, it has the potential (although not a certainty) to be more meaningful to the writer than a low-stakes writing-to-learn activity such as a summary-response essay.

Figure 8.4 provides another assignment, this one reported by Finkestaedt-Quinn and her colleagues ("Capturing"), and shows a similar level of challenge and engagement for student writers.

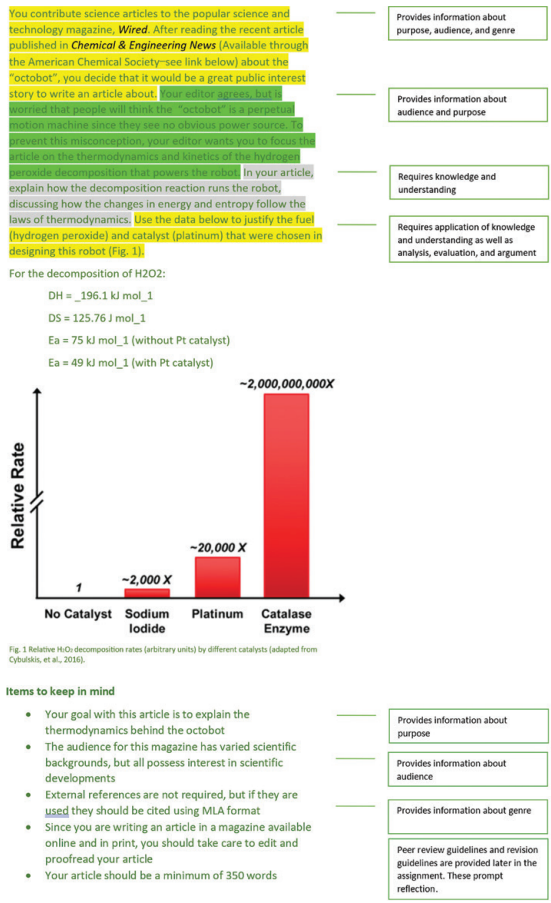

Figure 8.4. Annotated assignment for a chemistry course on thermodynamics and kinetics. Source: Finkenstaedt-Quinn et al., "Capturing" 933.

As shown by the annotations in Figure 8.4, the rhetorical considerations associated with explaining to readers of *Wired* how the octobot robot is powered are predicated on transforming the writer's knowledge of thermodynamics and kinetics into a form that is accessible to a general audience. This process will entail critical thinking activities ranging from developing their own understanding of thermodynamics and kinetics to reflecting on how to adapt that knowledge for their readers to applying that knowledge to data in the development of a justification for their decisions about using hydrogen peroxide as a fuel and platinum as a catalyst. The development of that justification will likely involve evaluating alternative fuel/catalyst combinations. Finally, the use of peer review and revision will entail additional reflection and planning, both to provide useful feedback to their peers and to improve the first draft of their article.

CONCLUSION

The straightforward distinction between viewing writing activities and assignments as either a means of supporting learning or a means of enhancing student writers' ability to communicate—that is, as either writing to learn or writing in the disciplines—is valuable. As an entry point into discussions about the role writing might play in classrooms, it serves a useful function. Once instructors have become familiar with this basic distinction, however, it no longer sufficiently conveys the complex set of roles that writing activities and assignments can play in STEM classrooms—and, for that matter, in any classroom.

Adding the concept of writing to engage to our discussions of the use of writing to support learning can clarify the wide range of uses to which we can put writing in our courses. Referring to activities as different as listing questions about a reading assignment at the start of class and contributing a section to an NIH grant proposal as writing to learn not only lacks precision but also contributes to a lack of clarity in our discussions of the potential benefits of using writing to enhance learning. The work reported by the Gere, Finkenstaedt-Quinn, Gupte, Halim, Moon, Petterson, Shultz, Thompson, and Watts research teams provides a strong example of how to use writing activities and assignments to engage students in course content in a way that goes far beyond working to remember and understand those concepts. Their work has deepened students' understanding of course concepts, supported their use of disciplinary conceptual frameworks and practices, and required them to engage in critical thinking about the information, ideas, and processes central to the course and its discipline. The assignments they have developed through their studies provide outstanding examples of writing to engage. In developing them, they have provided greater clarity about how writing-to-engage activities and assignments can

benefit faculty members who seek to improve student learning, retention, and critical thinking at various points in the curriculum and how students in turn will benefit in ways that allow them to move successfully through their course sequences and into professional work.

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