Enculturation in STEM

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Over the last seven years, I have spent time across three continents talking to scientists and mathematicians about their beliefs and attitudes and experiences related to writing in their respective disciplines. I have been impressed by the passion and insight with which most have talked about writing and its relationship to critical thinking, and I have often been surprised by how they engage in these practices. For example, rather than working from an *a priori* hypothesis, many researchers in the STEM disciplines compose backwards, from the results to the introduction. And when reading, many seem to move from the middle of a paper outwards, beginning with the results and method, using an extremely critical eye, and then perhaps scanning out to the introduction and the discussion, or dispensing with these sections altogether. Over and over again, I heard this same story from different scientists, as if it were a secret each alone had stumbled upon.

In addition, collaboration, conversation and peer review are very much part of the language of composition that takes place in the sciences (co-authorship, the hierarchies of disciplinary or interdisciplinary teams, the drafting process and the use of technology), but we who work in WID (writing in the disciplines) and WAC (writing across the curriculum) programs are constantly challenged: "How do we teach process in ways that are disciplinarily appropriate?" Historically, we haven't done this well. As Burton and Morgan observed on the training of mathematicians as writers,

> the novice may learn through using the existing models of published writing, through an apprenticeship of collaboration with more experienced writers, or through the often harsh process of peer review. None of these methods is designed to help learners to acquire the kind of knowledge about language that might enable them to be aware of what they might achieve by choosing to write in different ways. (450)

If many of those working in STEM have needed to become intuitive, self-taught readers and writers, then in order for students in these disciplines to be better prepared as thinkers and writers, there needs to be a pedagogy which addresses not only the genres but also the actual working strategies and practices of STEM. Accordingly, a theme of enculturation runs through this volume of *Double Helix*.

We begin with Peter Samuels' article, which addresses a much neglected area of investigation: the critical thinking and writing of research mathematicians in practice. He outlines the difficulties of researching mathematical thinking, and the limitations of past and present methods employed to capture it. He then introduces four alternative approaches: analysis of plan writing, activity transcripts, concept maps, and annotated drafts and transcripts. These approaches offer rich opportunities for researchers and teachers, both inside and outside of mathematics, to gain an understanding of the thinking and writing governed by the behaviours of mathematicians.

Brady Kathy and Tiffany Winn's research emerged out of their experience teaching mathematics to pre-service teachers. While they expected their students to hold unrelentingly

DOI: 10.37514/DBH-J.2014.2.1.01

negative views about mathematics, their research suggests otherwise. By inviting their students, in a guided, reflective lesson, to explore metaphors relating to their views and experiences of mathematics, Brady and Winn were able to develop a more nuanced view of their students' attitudes: a view that could, they suggest, be useful to teachers and students alike. This is a study that I hope others will replicate and extend since it challenges teacher perceptions and also invites complex reflection by students.

Denise Bressler describes a controlled study of middle school students designed to explore the effectiveness of collaborative augmented reality games in fostering critical thinking skills essential to the construction of scientific knowledge. The outcomes of this timely and interesting study present challenges to teachers in school systems—and perhaps beyond.

We stay in the middle school for Cory Buxton and co-researchers' exploration of the use of bilingual constructed response science assessments to support science enquiry practices and the acquisition of language of science in the classroom. There is much to be taken from this dense, rich study, but I would point in particular to their emphasis on the need for science teachers to embrace writing as a way of understanding how their students understand content, make choices of language, and learn to "take ownership of the language of science." I would also point to their call for more research into the work teachers and students *do together* in the classroom as they engage with challenging scientific questions.

Katharine Brieger and Pam Bromley's contribution to this collection, the first report from the field, is a practical example of how to integrate writing, critical thinking and peer review into a large introductory biology course. As they note, faculty are often reluctant to engage in supporting such activities, given limited resourcing and heavy workloads. The solution they explored—peer review workshops managed by writing fellows (under the joint auspices of the Writing Program and the Biology Department)—strongly suggests important benefits to students' writing and critical thinking.

Like Brieger and Bromley, Stacia Kefalos Vargas and Paul Hanstedt collaborate across disciplines—this time, physics and English—to develop science students' writing, deepen their learning, and affect their attitudes towards writing. Their research was conducted in response to a problem they perceived in student writing: "students seemed to default to form over content, style over thought." Their solution, a portfolio which includes students contemplating their own revision process, suggests substantial improvements in student motivation and attitudes towards writing. The formative assessment component of the portfolio was seen as positive by students and may very well have led to improved writing processes and learning. This report, like the one that precedes it, describes a process of instruction and assessment that mimics scientists' own processes. In addition, it encourages students to learn the language of revision and to become more intentional in their writing.

Irene Reed, Steven J. Pearlman, Carol Millard, and David Carillo take us back to the biology classroom for their practice-based report. Using a carefully designed rubric to assist peer review and assessment, the authors address the impact of a complex peer review system and show how it results in student perceptions of gains in skills and content knowledge, more effective engagement with the literature, improved capacity for teamwork, and changes in writing processes as well as products. Pearlman and colleagues explicitly link peer review back to the practices of research scientists and the culture of science.

For Tracie Marcella Addy, Catherine LePrevost, and Maura Stevenson, critical thinking is at the heart of all scientific endeavour. Furthermore, they suggest that students' preparedness to engage with critical thinking, prior to entering college, can have a major impact on academic achievement. Their report sees writing as a key to developing critical thinking and goes on to introduce two specific learning environments—the flipped classroom and problem-based learning—as ways of destabilising conventional classroom teaching. This is a preliminary report that invites further exploration.

In the final practice-based report in this volume, Gorman, Ingles and Mitchell describe the application of experimental pedagogies in a collaborative project born out of experience and rigorously assessed. Theirs was a considerable challenge: to enable their students to engage in original research while operating within a repeatable and manageable teaching framework. The process that is fully described in this paper is impressive in the way that it enables students to grasp inductively the processes of creating and communicating science. The outcomes of this project, a collaboration between a science teacher and a writing program, are impressive, both in terms of the impact on student learning, and in the reflective implications for the teachers. The pedagogical approach explored in this paper looks to achieve a "significantly changed relation between students and academics," and a learning environment in which the classroom has become a true research context, one which not just mimics but replicates "the ways academic staff themselves research and learn" within the STEM disciplines.

In his review of Michael Tomasello's *A Natural History of Human Thinking,* Adam Katz points to the pedagogical consequences of Tomasello's work, particularly in relation to language use and thinking and social context/engagement. Katz's reading is perhaps especially apt, given the theme running through this volume: the making of science within a social community, and the pedagogies that enable our students to, in a variety of ways, step into that community.

Finally, we include in this volume a letter from a team of researchers in Ireland. Alison Farrell and her colleagues respond to an article from Volume 1 to reiterate the relationship between writing and critical thinking, but also to emphasise the importance of "critical literacy." They are working on a set of "guiding principles" for developing critical literacy, which focus on the importance of developing students' disciplinary identity, empowering faculty, and finding opportunities for collaborative work in this endeavour. They remind us that a diversity of expertise is needed—from not only writing and disciplinary experts, but librarians, and teaching and learning consultants, too. We look forward to reading more of their work in *Double Helix.*

The work outlined above suggests effective ways of enculturating STEM students. But I want to end with a quote from Gorman, Ingles and Mitchell's report which, to me, sums up much of what we're aiming to achieve in this volume of *Double Helix*:

> The course has achieved our aim of enabling students to participate in "the ways academic staff themselves research and learn in their discipline or professional area" (Healy and Jenkins, 2009) … . This includes the discovery of a research problem, the formulation of hypotheses, the design and execution of an experiment, and the iterative processes of writing, review, reading, research, and rewriting. Much of this work is collaborative, with both current peers and past peers, and in anticipation of future peers…. Peer review also contributed to students learning to make judgements that would hitherto have been the preserve of the academic (Sadler 2010; Bloxham 2009; Shay 2005). Eventually, I hope that their work may be developed into a multi-authored published article; if this becomes possible, it will mark a significantly changed relation between students and academics.

If, as teachers, we can achieve at least some of this, then we are well on our way to developing in students an understanding of the complex relationships between writing and critical thinking in their respective disciplines, and to preparing them to be more intentional and more adaptable as writers and thinkers.

Reference

Burton, L., & Morgan, C. (2000). "Mathematicians Writing." *Journal for Research in Mathematics Education, 31*(4), 429 – 453.