Writing and Learning in View of the Lab: Why “They” Might be Right

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ABSTRACT

To interrogate the field’s current understanding of writing as central to learning in the sciences, this study offers results from a qualitative, emic study of college students and their scientist mentors at work in an NSF-sponsored Research Experience for Undergraduates. I observed that the work of this professional research laboratory mainly recruited and developed literacies, such as manual dexterity and visual acuity, other than language-based ones. Describing here the various laboratory activities that fostered higher-order thinking and knowledge transformation, I conclude that “writing to learn” research must consider how writing fits in with an ever-developing understanding of the complexity of learning.

KEYWORDS

Writing, learning, science, undergraduate education, laboratory research

Recently, composition scholars have taken to publishing in scientific journals to advocate for new approaches to writing in science classes. Christopher Thaiss and colleagues have argued in the *Council of Biology Educators Life Sciences Education* journal, for example, that we need to know more about the writing tasks that promote learning in the sciences; they recommend more collaborations with science faculty to test and report best practices (Reynolds et al.). Cary Moskovitz and David Kellogg in the pages of *Science* argue that because students “do” instead of “learn about” science, writing assignments should be integrated into laboratory settings and reduced to “highly condensed” tasks (“Inquiry-Based Writing” 920). These publications recognize that Writing To Learn (WTL) has not achieved the level of acceptance or success in science instruction that it has in other areas of the curriculum. The steep hill that WTL pedagogies still have to climb to reach into the sciences is further evidenced by an exchange between a physicist and Moskovitz and Kellogg in the "Letters" section of a subsequent issue of *Science*. Michael Goggin, the physicist, argued that Moskovitz and Kellogg had "focused on teaching writing in the introductory science course at the expense of teaching science" (Goggin 524). Moskovitz and Kellogg responded to Goggin that science lab courses "offer an essential opportunity for students to learn about the practice of science, and this practice includes presenting one's work in a clear and compelling fashion" ("Lab Course Goals" 524).

Had Moskovitz and Kellogg published their article in a composition journal rather than in *Science* where it reached an audience of scientists, it is unlikely that anyone would have voiced Goggin's concerns, particularly as they question the link between writing and learning the practice of science. As a field, compositionists have accepted the enmeshment of writing and learning since the 1977 publication of Janet Emig's "Writing as a Mode of Learning." Emig's claim that writing is integral to the process of knowledge creation, rather than merely the report of knowledge gained, helped launch the WTL movement. As John Ackerman has subsequently observed, the notion that students "write to learn" rather than learn to write is practically a charter of our field, having become the rationale for expanding writing and composition programs with requirements in every corner and at every level of the undergraduate experience. The response Moskovitz and Kellogg gave Goggin could have been supported by numerous citations of WTL literature.

In this article, however, I suggest that we resist for a moment the ready response to scientists who question the relationship of writing to learning in their fields. I read in Goggin's objections not so much a challenge to the notion that writing can contribute to learning science, but an assertion of the value of other activities important to learning that vie for precious instructional time. I further agree with Reynolds et al. that we do not yet know enough about writing in the sciences, particularly in those laboratory settings Moskovitz and Kellogg had referenced. To contribute more data to this effort, I offer here the preliminary findings from a qualitative study of undergraduate writers and their scientist mentors at work in a laboratory setting. "The Lab" is my pseudonym for the internationally renowned research field station in the United States that was the site of the Research Experience for Undergraduates program (REU) I observed in the summer of 2011.[1] During the program I followed 10 REU students and their mentors while they were, as their mentors put it, "doing" science; that is, students were embedded in funded labs where research was being conducted for publication purposes. As researchers have noted, there are significant differences in purpose, range, and exigencies that distinguish classroom from professional laboratory work (Hanauer et al.; Wenning; Zachos). As one REU mentor described the role of students in this non-degree granting setting: "They're part of a research program and they are contributing to a research program." Where better to learn the genuine practice of science?

My original intention, informed by WTL literature, was to determine what forms of writing best led to learning in this environment and to report them. A comment made by Professor Mark Lauten, one of the co-directors to the students, however, changed my plans. Introducing the requirements of the program in the first week of the summer, he told the students that their capstone writing project would be posters rather than papers because, "We could have required you to do a paper, but then you would have less time to do research." Lauten further admitted that he felt the poster would be "enough of a problem." Lauten's was not the only concern voiced that summer about writing taking precious time from research. When I asked another mentor how he taught students to keep a laboratory notebook, he responded, "I basically want them to have more of the hands-on experience than trying to worry about teaching them about lab notebooks during the course of this, because I think they have plenty of other opportunities to get that kind of thing." [2]

Although such comments, like Goggin's, seem on their face to marginalize writing and thus challenge decades of WTL research and practice, my research suggests that many of the REU mentors were rather attempting to address an imbalance of attention; in their home institutions, they felt, writing was already well-suffused throughout the curriculum, to a far greater extent than laboratory practice. Significantly, none of the informants I spoke with disputed the importance of writing to the progress of science. As one of the REU mentors put it, "If you're going to get into biology, that's a profession of writing." While acknowledging the importance of writing, however, REU mentors spoke more often of the need for programs to develop abilities, aptitudes, and capacities they considered also critical for success in the sciences, including: the manual dexterity necessary to conduct experiments, the ability to tolerate long hours of working both independently and with others, and the capacity to pursue projects over long periods of time.

The mentors' goals largely reflected those of the sponsor of the REU program, the National Science Foundation (NSF). The NSF established the Research Experience for Undergraduates program in 1987 to make up for deficits they perceived in science instruction in traditional classrooms. The initial goals of the program were "to expand student participation in all kinds of research" and to "attract a diversified pool of talented students into careers in science and engineering" (NSF, "Overview"). In the first three years of the program's existence alone, the NSF spent 37 million dollars on 11,000 students placed at hundreds of sites. The NSF evaluates REUs by asking students if subsequently they planned to apply for graduate school, or even if participating in the program had clarified their career path. Although initiated in a moment of perceived literacy crisis in response to declining numbers of students applying to graduate school in scientific fields, the pedagogical approach of intensive laboratory or field research proffered by the REU program is hardly radical. Scientists, Neal Lerner reminds us, have embraced learning by "doing" at least as far back as the spread of science education in the late nineteenth century, following the influence of Harvard professor Louis Agassiz who advocated experiential learning. As one mentor, Professor Rudek, maintained, the "doing" of science in the lab was vital to learning science: "If you put students in the laboratory they learn science way better than ten times the hours in the classroom—because they're *doing* science. They're *doing* science." Indeed at the Lab, "doing science" left little time for writing (other than writing to record) and the composing task of the poster did, as Professor Lauten's comments suggested, cause a problem. By the last week of the REU, some students had no real data to communicate, one summer being insufficient time to let many experiments run their course. Other students were so engaged in collecting data that they had little time to organize it for presentation. In the view of the Lab, however, preparation of the poster was not of major concern; the primary purpose of the REU was to participate in laboratory activities.

The ten weeks of intensive research were above all designed to help students learn about themselves. Students were not only to collect data, but also to develop the embodied understanding of what it felt like to collect that data (or fail to), day in and day out, day after day after day. The REU program, I came to understand, functioned as a kind of lab inside a lab, putting students in a genuine scientific context to see which ones might be drawn into science as a career, and which ones might consider a different path. According to Professor Lauten, even students who decided not to pursue graduate school after attending an REU represented a good investment for the NSF: “I think you’re equally successful if they decided they hate it as well as they embrace it because the NSF would much rather spend $10,000 on a student to find out that they don’t want to do science than a quarter million dollars for their PhD and find out then.” All the senior scientists I spoke with understood “science” as a project that extended over vast stretches of time; research projects were routinely passed down from one generation to the next. Building that next generation of scientists was therefore ever foremost in their minds. However, in order to think in terms of generations, they appreciated individual difference: some students, they knew, would show affinity for the work, and some would not. Unless students experienced the lab, however, they would not be able to know enough about the practice of laboratory science to determine if that path was right for them.

> **“*Manual activities such as those I witnessed students doing at the Lab are rarely considered in WTL literature at all. Yet, as I observed at the REU, research at the Lab required a great deal of physical labor and repetitive manual activity as an instrumental component to student learning of science.*”**

After observing and interviewing the students of the REU through their summer, I concluded that the co-director, the mentors, the NSF might have been right: students weren’t writing much, but they were learning a great deal. Although students periodically made written and oral reports of their progress, wrote abstracts for conferences, and all wrote and delivered a poster for the symposium, students spent most of their hours engaged in manual activities: taking photographs, handling chemicals, mixing solutions, positioning ice-fishing shelters, disposing of carcasses, and watching blips on computer screens. Hanauer et al.’s conception of scientific inquiry explains why such manual tasks are critical to the practice of science. According to Hanauer et al., scientific inquiry is a multimodal process involving not only knowledge of the discipline, relevant questions, scientific principles, and how to present them, but also “physical knowledge”—the knowledge of how to perform laboratory tasks. Based on my observations, I would add to Hanauer et al.’s composite of concepts and skills involved in learning science a few more that relate to knowing *about* the lab as well as knowing what to do in it, among these: understanding the amount of repetition it takes to get results, recognizing the pace of scientific research, being able to handle the hours and the environs, and developing the capacity to challenge—yet work with—one's collaborators.

By many educational standards including those endorsed by WTL research, the manual tasks students performed at the Lab, and the degree to which those tasks had to be repeated daily, did not demand "higher-order" thinking. "Higher-order" thinking, according to Reynolds et al., requires "a process of knowledge transformation" rather than, for example, mere recall (17); the task of WTL researchers, Reynolds et al. further argue, is to determine what forms of writing tasks best evoke that process. The educational embrace of developing higher-order thinking tasks follows on Benjamin Bloom's influential taxonomy (developed more than fifty years ago), where recall is presented as the lowest level of cognition, and analysis, synthesis, and evaluation register further up the chain of cognitive demand. According to this taxonomy, the most frequent use of writing that I witnessed at the Lab—writing to record—would require less cognitive effort than synthesizing knowledge to compose a poster. Manual activities such as those I witnessed students doing at the Lab are rarely considered in WTL literature at all. Yet, as I observed at the REU, research at the Lab required a great deal of physical labor and repetitive manual activity as an instrumental component to student learning of science. When we look at the sciences, in other words, we need to broaden our framework for what counts as learning beyond writing.

The findings of this study have implications far outside the lab, or even science. My study of the Lab underscores Mike Rose's call for the field to embrace "a multidimensional model of intelligence and a conception of knowledge that doesn't separate hand from brain" (215). Manual skills, Rose notes, are learned not primarily through books, but through observation and doing. Rose argues that while schools tend to focus on intelligence from the neck up, much of what we consider intellectual learning has significant manual components, and much of what we consider manual labor can only be learned through significant cognitive effort. I add this study to Rose's challenge to culturally maintained boundaries between intellectual (high) and manual (low) skills and to the assertions of the relative value of them to the academic enterprise. I conclude that "writing to learn" research must consider how writing fits in with an ever-developing understanding of the complexity of learning.

METHOD AND PARTICIPANTS

Two questions initially drove my investigation:

How did students and mentors understand learning in the lab?

How did students and mentors understand the role of writing in that learning?

To answer these questions, I conducted audio-recorded semi-structured interviews (Fontana and Frey) with REU students toward the beginning and near the end of the ten-week session of mentored laboratory research. I solicited students' educational histories and accounts of how they anticipated and reflected upon the writing required in the REU. I asked students about the relationship they perceived between this writing (including laboratory notebooks and informal writing) and the practice of research. I checked their retrospective accounts of their writing practice against the texts they produced during and prior to the REU. I conducted semi-structured interviews with mentors to ask how they used writing to mentor undergraduate students, about their own histories of writing in scientific and non-scientific settings, and about how they understood the purpose of writing in the process and presentation of scientific research. I observed students at work in their laboratories and attended lectures with students and mentors. I attended weekly meetings of the REU group where research-in-progress reports were made. Lastly, I attended and audio-recorded a peer group review session where REU students, applying to a national conference for under-represented students in the sciences, read and commented on each other's abstracts.

All ten undergraduate students in The Lab's REU program participated in the study as did ten of their eleven mentors. Through NSF funding, the Lab provided students with a stipend of roughly five thousand dollars, plus room and board for ten weeks (NSF, "Overview"). Like other REU sites, the Lab recruited a diverse group of students from disparate institutions where, for the most part, opportunities to participate in laboratory research programs were scarce. My student participants therefore included six women (including one American Indian, one Asian American, and one African American) and four men (one Puerto Rican, another of Puerto Rican and Republic of India ancestry, and one identifying as Chicano American). The exact areas of research the students conducted included molecular and cell biology, neurobiology, physiology, developmental biology, ecology, and evolutionary biology. In addition to their lab work, students were responsible for presenting at the end-of-summer "undergraduate research symposium" (there were some concurrent undergraduate programs also presenting) and for composing the poster about their research. They were also responsible for attending weekly meetings of the REU group to share research quandaries and to learn about the profession from the co-directors and other guests.

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Faculty mentors participating in the REU from under-represented groups included one who identified as Latino, one as American Indian, and another as Chinese American (though he did not consider his demographic typically under-represented in the sciences). In contrast to the proportion of female students, all but one of the mentors I interviewed were male (the mentor who declined to participate was also female). Mentors came from various home institutions, though some were year-round affiliates of the Lab. All were senior scientists with national and international reputations. Perhaps not surprisingly, then, one aspect of student diversity that this program did not reflect was variation in achievement level. Each student could boast of a significant history of educational achievement that had propelled them to the top of a pile of 190 REU applications. (The following year, the co-directors would choose a class of eleven students from a jaw-dropping 390 applications.) In their review of applications, the co-directors sought to identify those students with the greatest interest in science research as a career choice.[3] They told me they wanted to invest their time and effort in future scientists, not future doctors.

The distinction the mentors frequently invoked between scientists and doctors was one that might have escaped me had I not been taking an emic approach to data analysis. Emic research emphasizes constructs and terms advanced by study participants over those emerging from outside the research site (Lett). For example, while an expansive definition of "writing" in the laboratory would include outputs from computers (cf., Latour and Woolgar), my informants did not consider such outputs to be writing, therefore I did not. Additionally, rather than measure my informants' learning according to an outside rubric or standardized measure, I adopted informants' understandings—largely consistent among them—of what counted as learning. My "a-ha" moment came the day I realized that the people whose learning I studied had been themselves studying learning, albeit on the neuronal level, on animals that learn but do not write. Where writing scholars might consider writing tasks in terms of those that evoke "higher order thinking" and those that do not, neuroscientists examine "higher order association areas" in brains of monkeys and rats. Clearly, activities other than writing can induce the transformation of knowledge we understand as higher-order thinking. My informants' questions about my questions slowly began to erode my faith in my categories: When I talked about writing to learn, for example, they asked, exactly what kind of learning did I mean? Listening day after day to the terms they used to discuss learning, I began to consider a broader framework for learning, and a narrower one for writing. In the past few decades, neuroscience has worked to specify the reach and limits of different cognitive activities through studies that could inform WTL. Recent research in neuroscience, for example, has tantalizingly identified writing's uniqueness from other composing processes; studies of subjects with brain injuries that impair writing, but not drawing or speech, for example, have shown writing to be an activity that engages very specific parts of the brain (Bormann, Wallesch, and Blanken; Flaherty). For the purpose of unbundling writing and learning, I began to ask: What can you learn by trying to isolate a neuron six days a week for two months that you can't learn by writing?

Ultimately my aim in taking an emic rather than etic approach was to highlight forms of disciplinary difference that might make a difference in how writing and learning are understood by participants. I believe there is viability in exercising both emic and etic frameworks in our research, and that neither should supplant the other. I would offer, however, that it is important from the standpoint of our roles as composition and literacy scholars working in the interdisciplinary environment of the university to phrase our findings in terms our institutional partners would find meaningful. To that end, I asked several of my informants to read a draft of this article in preparation and incorporated their comments into the revisions.

"THE MOST BORING JOB ON EARTH": THE PARADOX OF THE LAB

One paradox emerging from my interviews was that many of my informants told me how exciting science was at the same time as they told me how boring it was. They felt the way science was presented in traditional educational settings (those unlike the Lab) often failed to capture the imagination. My informants were nearly driven out of science by previous experiences in classroom "cookbook" labs where the answer was already known, or could be Googled, where no new knowledge was created, and where nothing rested on the result beyond the grade. Professor John Rudek observed of the rote memorization approach taken in the lower grades: "We just beat it out of them, it's so boring and there is no inquiry." Professor Allison Kent, a neurobiologist mentor, recalled even labs at an Ivy League college as stultifying "because I hated repeating someone else's experiments." A history major in college, she found instruction in her lab courses, compared with that in her humanities courses, "dry… disconnected from your own life, and from the world, and from humanity in a lot of ways." If an unengaging lab was a regurgitation of someone else's experience, the report of that research was a regurgitation of regurgitation. "There wasn't much variation in what you could do or say; it was sort of, everybody had to do the same thing," Kent remembered of college lab reports. Minimal learning was attributed to classroom labs. In contrast, students and mentors alike characterized with enthusiasm what was going on at the Lab as "real science." "Real" science meant pursuing a question that no one had answered. The excitement was in not knowing what was going to happen. The results of real science mattered.

Mentor and undergraduate descriptions of the process of "real" science nonetheless invoked boredom as often as did their recollections of "cookbook" science. One mentor observed of a vital component of data collection in his lab, "It's not the most entertaining thing to be watching small particles move across the screen." Another mentor explained that the progress of science depends upon scientists doing repetitive physical work such as running DNA samples—"the most boring job on earth," as he put it: "There's a lot of boredom in doing research. And we also tell all the undergrads that when they first get here. We say, 'Look, there are certain tasks that you have to do, and that I have to do, every day that are just repetition, tedium' . . . . It's just things you have to do. And that, to me, is all part of it." This mentor's observation reveals that students who have difficulty doing the disciplined work of repeating tasks have, in fact, difficulty "doing" science. "Doing" science according to Rudek also demands a sense of expanded time as well as the patience to pursue repetitious tasks through the months, or even years, required to achieve publishable results. He remarked to me that few people appreciate how many years of lab work are necessary to produce any given "fact" in a textbook: "Because it seems that it is all worked out, you pick up a biochemistry textbook and they have this nice picture of a cell and here's the nucleus and here is how it all works. Gosh, you think of the thousands and thousands of person hours that went into understanding that." Rudek observed that when students first grasped the slow progress of science, the Lab would "lose people for the right reasons": "I had a student who after about a month said, 'This just isn't for me.' He said, 'I just thought it would move a little faster.' He's now an air traffic controller at London's Heathrow airport." My informants collectively expressed that repetitious tasks, conducted over long periods of time, were essential to achieve novel results. Paradoxical though it may seem, mentors had to test student capacity for boredom to see if they could be excited by science.

Professor Rudek's REU mentee was Madeline, an African-American rising sophomore from an Ivy League university, the youngest of the REU students. Madeline was extremely disciplined and had no problem with repetitive tasks: She ran cross-country for her college's track team. When she wasn't in the lab that summer, I would often spot her on the roads miles away, running to maintain her fitness. In our first interview she told me that she found the purpose of Professor Rudek's lab—examining the effects of arsenic on human beings—inspiring. In her second interview, however, she admitted that she found the actual activity of Rudek's lab "boring": "I'm not so sure if I want to keep working in cell cultures because that gets a little monotonous and boring when you're pipetting like 96 well plates of cells all day." The *questions* that motivated the research in her lab, with their potential to improve lives, she considered worthwhile. She enjoyed the *communication* challenge of conveying results to people unfamiliar with the research. However, the *physical activity* she associated with research on her model organism, the actual activity necessary to obtain and communicate those results, she found "monotonous and boring." Her time at the REU resulted in clarifying her career path. She concluded that she did love cell culture lab work, but imagined herself working some day on a project focused on a more dynamic model organism.

REU student Carol found her summer also clarified her career path, but her vision of her future took her out of the lab altogether. Her experience at the Lab bore witness to the wisdom of Professor Lauten's commitment to ask every undergraduate who approached him for advice about graduate school: "Do you want to work outside or inside?" Carol, a rising senior from a small liberal arts school, who quickly distinguished herself among peers as being both self-directed and comfortable knee-deep in marshes, would have answered that question, "outside." Although the daughter of a college biology professor, she described herself in her first interview as "not really a lab science person" and "the odd one out" at the REU.

Carol's interest before coming to the Lab was in field ecology. In college she had completed a research project on milkweed height; in another course she had been required to observe nature and then write field notes in the style of Thoreau. Most formative, however, were her experiences outside of the traditional curriculum: month long back-packing trips in Wyoming and Alaska during high school summers; field work in East Africa through college study abroad. At the Lab, Carol travelled once or twice a week to a remote site to change the batteries of cameras poised over tree canopies, and to take leaf samples. Yet the purpose of those trips, examining the effects of climate on chlorophyll levels, required more indoor laboratory work than she had imagined. By the ninth week of the program, she knew she was not a laboratory scientist, but still considered herself a researcher: "I wouldn't want to do this kind of lab work everyday forever . . . . I realized that there are so many other types of research that aren't [at the Lab] like animal behavior and population and wildlife things." She revealed that over the summer she had developed an alternative curriculum for herself that allowed her to learn about animal behavior while doing the "super repetitive" leaf analyses required in her lab:

> I have been listening to a ton of stuff when I'm in the lab, because a lot of the chlorophyll readings are super repetitive, just like pipette this, and grind this, and put it over there. And so I listen to a lot of like radio or podcast things—a bunch of things about people studying apes, like bonobos and chimpanzees, so that stuff has been really exciting to me.

The cases of Madeline and Carol suggest that the experience of time spent in the lab doing manual tasks over and over vitally clarified what kind of scientist they would like to be. It's hard to know if one likes pipetting "96 well plates of cells all day" until one has the opportunity to do it, and hard to know what it's like to work inside if one has only ever worked outside. From the REU's point of view, both students' experiences were successful, as they resulted in learning students would not have been able to do at their home institutions.

Yet the students learned more than about their individual affinity for science through repetitive work. Repetition of manual tasks was essential for them to learn the practice of science, itself. Significantly, my informants noted that they learned laboratory techniques by watching and repeating them over time. Writing played a very limited role in learning, for example, how to make solutions, pipette, and take measurements. When they did mention the role of writing in learning these techniques, they invoked writing as memory aid. But mostly, they invoked practice. As Carol observed: "The spectrophotometer is one of the big procedures that I do and at first I was like, how am I going to remember these things? I don't know if I should be writing it down . . . . I think with practice it gets better." Some techniques were harder than others, however, such that ten weeks of practice provided insufficient time to master them. As I discuss below, learning through repetitive "doing" over time is not simply an alternative way to learn things that could otherwise have been learned through writing. It is a different kind of learning that engages different parts of the brain altogether.

"WITH PRACTICE, IT GETS BETTER"

"I'm never bored in my lab," Stefan told me. "If I'm not doing the solution, I'm doing the pipettes. I have different tasks at the same time." Stefan, a rising junior from a mid-tier university in Puerto Rico, was assigned an REU project that was daunting in its requirements for manual dexterity. His mentor, Professor Kent, told me that the experiment she had assigned Stefan was so difficult that pulling it off without assistance was "like sailing a boat by yourself."

Stefan rose to the challenge, finding excitement in the very activities that fellow multi-tasker Carol had found onerous:

> The solutions go like [snaps his fingers]. I make 500 ml and that goes in three days of work. That solution has to be made, pH'd, and you have to check the concentration with a machine. You have to be very meticulous about the solutions because if you make a sloppy

> solution, you're going to get sloppy results. It's trying to get the least amount of sources of error; it's very important.

Stefan perceived each step in the experiment as just as important as every other step. As Stefan noted, "it's very important" that the solution be made precisely. If the task isn't done correctly each and every time it is repeated, science itself doesn't happen.

Stefan had a naturally inquisitive mind. His lack of boredom at the Lab was a stark change from life at his home institution where he was, he told me, frequently bored. Although he achieved a perfect score on his college math boards and was admitted to the premier engineering college in Puerto Rico, poor high school guidance steered him toward a less challenging college closer to home. There, he could—and did—Google the results to his labs. He had majored in biology in part to satisfy family desire (his parents were dentists, pro-medical career, and, as he put it, "anti-research"), but also to escape his growing obsession with computers: "I was so into computers, I was turning into one." By seventh grade, he knew how to program in five languages. By ninth grade he was writing and selling games. By 12th grade, he realized he had to pick a college major other than computer science because his college would have no courses to offer him: "I knew how to program perfectly. It's like knowing you have a fluent accent." He also wanted a social life, and if he continued to program, he realized, he would never go out.

Despite his professed desire to get out more, Stefan's ability to sit indoors and stare at a screen for long hours was good preparation for the chief activity that consumed his days at the Lab: patch clamping, an electrophysiological technique to isolate, observe, and record the activity of ion channels in the neuron. Patch clamping for Stefan was similar to playing video games: "You have a TV and you have controls, like joysticks." However, the technique required far greater manual dexterity. Stefan derived the know-how to do the technique from several sources. He gleaned the most from shadowing and listening to Kent: "She's like blalalalalala and I try to remember everything." He visited several labs that also used the technique to observe their set-up (the position of tables, screen, and knobs). He read a manual but didn't find it helpful, because, as he put it, "the small details are what matter the most. Like how much pressure you should do on this, how fast you should go." During a meeting of the REU group, the co-directors gave him additional tips from their accumulated years of patch clamping experience. Stefan also read a textbook on the neuron. He took a few notes. His active search for advice on technique shows that he understood that patch clamping demanded a great deal of "physical knowledge," as Hanauer might say. It was like he was trying to improve a golf swing by asking pros for tips. Based on the advice he received, he changed elements of his set-up. He showed me a photo of his new set-up and explained, "You see that platform there? That platform I lifted one-fourth of an inch, and that made a huge difference."

Stefan rarely referred to his lab notebook, in which he had inconsistently recorded his own attempts at patch clamping: "It's sloppy and very fast and weird, so my notebooks are very incomprehensible to many people." Stefan was not underperforming by not writing a lab notebook diligently and neatly. Professor Kent confessed that even as she stressed the importance of keeping a lab notebook to record an experiment that might be the basis of a publication, she had never been a steady note-taker: "My mentors were constantly annoyed with me because I wasn't really writing as well as I should have been. And that was a problem. Even now, I'm not—I'm pretty bad, I must say, about keeping a lab notebook." Professor Lauten averred, "I'm the worst example of keeping the lab notebook in the world." In my last interview with Stefan, I discovered that his real lab notebook was not kept on paper. If writing is the legacy record-keeping tool of the scientific laboratory, Stefan, whose relationship to verbal and written language was fraught due to a learning disability, had found a modern alternative. In the middle of recounting the process of going from whole rat to hippocampal slices, he reached for his phone: "I have a video. You want to see it? I have a video of everything." [Plays video from phone.] "That's the blade that cut me."

Stefan described his main method of learning as "trial and error." According to Stefan, it helped him to watch techniques performed, and then do them himself, again and again. He emphasized the importance of his daily routine to his learning: "I go to work at 10. I get my rat, dissect the brain out and then I do the slices. Then I cut the slices with a knife and get these pieces of brain, the hippocampal slices . . . . The first time that you see it, it looks easy, but it's actually hard. At first you're slow, but after a couple of times, you get faster. It's practice." Stefan, like Carol, had maintained that with "practice," their work at the Lab got better.

But on the scale of required manual dexterity, what Stefan had to do was a few notches of difficulty above what Carol had been assigned. Stefan, arguably, spent his summer performing brain surgery. As Mike Rose has observed, surgeons learn by feel as well as sight: "The surgeon's knowledge of anatomy has to be physical. He or she will be working in tissue, moving it, tugging on it, cutting into it . . . . One thinks one's way through an operation by feel and image as much as by proposition." A surgeon's visual acuity develops through prolonged and repeated immersion in activities that, as Rose explains, discipline perception. As one resident Rose interviewed explained, "'You develop an eye for what looks good and what doesn't . . . . You get to the point where you feel comfortable looking at something and evaluating it'" (151). Stefan's description of his learning process appeared to be similar. Describing the importance of visual acuity needed to assess usable samples for patch clamping, he said: "You actually see it when you're slicing the brain. If it comes out like ham slices, that's good. But if it's a dead brain, it just crumbles apart." Stefan had fewer than 60 seconds to harvest the slices before the brain would become ischemic. If he couldn't "see" the difference between a good and bad brain slice, his experiment would fail. He needed his eyes to guide the micromanipulator. And he needed all his fingers. Working alone in Kent's lab on a Saturday, Stefan injured his finger. The gash was deep enough that he could not operate the micromanipulator and was forced to get stitches. Not wanting to miss the data he collected, he finished the experiment before going to the emergency room, but he could not collect data for the next few days while the wound healed. Even one day of not practicing was a loss to him, for both data collection, and for the refinement of this skill. Because refinement of Stefan's sense of touch took more than even the ten weeks allotted by the REU, Kent offered him an additional semester of assistantship at her home institution.[4]

LEARNING WITHOUT WRITING

The field of composition has been interested in the brain's role in writing and learning since Janet Emig argued, "Writing involves the fullest possible functioning of the brain" (125). While Emig argued that writing involves both hemispheres of the brain, we know now (truly we knew even then) that the brain is far more complex than the bi-hemispheric model Emig drew upon. A failure to acknowledge the brain's complexity, its involvement in all forms of learning, could lead to over-estimating the importance of activities that involve primarily language centers of the brain to learning in all fields, as Emig did in articulating the value of WTL.

Watching the students of the REU, I began to consider what I had learned in life without writing. I recalled learning ballet for about thirteen years, during which time I never picked up a pen—was never asked to and never wanted to. More recently I picked up tennis, again taking lessons that never involved writing. Yet my forehand has improved. I shared my thoughts with Professor Kent who explained why learning physical skills does not prompt people to want to write; she articulated the difference between forms of memory that engage language centers in the brain, and those that engage mainly procedural brain regions:

> Kent: A lot of athletic activities don't make people want to write, because that would be associated with procedural brain regions.
> Catherine: Is that related to muscle memory?
> Kent: Yes, exactly. So even though you're working on learning how to ski or play tennis or something, you don't really feel like writing it down because that maybe doesn't interact so much with language centers of the brain.
> Catherine: [Nodding towards Stefan, patch clamping in the lab] How much of what he's doing is that?
> Kent: Oh a lot. A huge amount. So he has a huge amount of procedural memory going on.
> Catherine: That's different from episodic, and it activates different centers of the brain?
> Kent: Yes.
> Catherine: Because writing, you know, it is physical, too . . . . That's what makes it complex.
> Kent: That's true. But it's a kind of physical memory that is quite simple. It wouldn't be like learning to play the piano . . . . [Writing] is so subconscious that you don't even think about it, whereas *what* you're writing, you're thinking about more.

Several kinds of memory are currently recognized in neuroscience, notably episodic, semantic, procedural, and working (Eichenbaum). Of these four kinds of memory, procedural alone involves the basal ganglia as well as the cerebellum (Budson and Price). The basal ganglia are associated with the development of learning routines and habits. With the exception of research that acknowledges the significant cognitive effort handwriting requires when it is first learned (e.g., Connelly et al.), little research on cognition and writing discusses procedural memory. Beyond the stage of acquisition of handwriting and keyboarding, the procedural memory required for writing is, as Professor

Kent argued, minimal. What Stefan was doing at the Lab, however, involved "a huge amount" of procedural memory development. He was not simply gathering data in order to learn through a subsequent process of language-engaging analysis. By patch clamping, by physically disciplining his hands and eyes, he was learning something that took at least as much cognitive effort as writing a good thesis statement.

I do not seek here to provide a complete account of learning and the brain. The understanding of neuroscience that informs my discussion here is on a level analogous to high school reading knowledge of French. As a further caveat, my informants would be the quickest to acknowledge that neuroscience is far from understanding the brain in all its complexity. Stefan was working on improving that understanding by studying long-term potentiation, or the formation of memory. Because Stefan never did complete his experiment, his poster concentrated on his efforts to troubleshoot his set-up. The conclusion of his poster acknowledged that ten weeks had not been time enough to get results: "There was not sufficient data and time to be able to draw conclusions. Nevertheless, troubleshooting the technical aspects of the experiment was important for eventual data acquisition. The experimental results will enhance knowledge of the function of BCL-xL in the brain." Even with all these caveats, however, current basic neuroscience presents questions about the centrality of writing to laboratory science. Certainly, Stefan would have learned more had he been able to complete the experiment. However, even though Stefan did not have the opportunity to interpret results that summer (and the experiment remained uncompleted more than a year later because senior scientists and post-doctoral students are still trouble-shooting the set-up), he had, in fact, learned. The case of Stefan suggests a challenge to the conception of writing as the singular consolidator of learning. Though Michael Carter suggests that "it is primarily in writing the lab report that doing becomes knowing" (388), Stefan's procedural knowledge of how to isolate a neuron would be primarily refined through practice, not through writing. This knowledge would remain with him as long as he practiced it, even if he never wrote about it.

If it is possible to learn without significant writing, is it also possible to write without significant learning? My findings suggest that possibility. At the first meeting of the REU group, the co-directors had asked each student to describe their laboratory's research, insofar as they understood it after one week. Stefan's account of his research was halting: "It's so much information . . . . Let's see, what else about BCL-xL. It has to do with calcium concentration, too . . . . I'm still like a newbie related to BCL-xL, but I hope at the end I have a better grasp." Madeline had prepared a PowerPoint to describe her lab's research; however, in presenting it, she observed that she was still swimming in language. Describing the effect of an agent she was working with, she said, "It's an inhibitor at lower dosage and an enhancer at higher dosage. Sorry, I screwed that up, it's an enhancer at lower dosage and an inhibitor at higher dosage." She admitted to the other REU students that the material was "still a lot of jargon" to her after one week. Her lab, she explained, had not yet begun the experiments because they hadn't yet received their cell lines.

By the end of the summer, however, Madeline could describe the work of her lab fluently. I asked her in our last interview to look over the PowerPoint she presented in her first week and to tell me what she might have done differently were she to present the material in future. She found her past performance easy to critique:

> I can tell from the second slide already. I said that it alters serine hormone receptor mediated gene regulation, which is something that I had read in a paper, but I didn't really understand how it did that . . . . So now I know it's actually doing something to the function of these receptors so they can't bind properly and start transcription and that's why we'll see an enhancement or inhibition.

Although she had presented nothing factually erroneous in that first week, Madeline said of her PowerPoint, "I think that's something that I wrote that I didn't fully understand . . . . It says it alters gene regulation, but I could have gone into more detail about how. Well, now I could."

Madeline's account reveals that as she composed her PowerPoint in the first week of the summer, she was writing, but not learning significantly. The learning happened later, weeks later, after significant time working in the lab. To prepare for her first report, Madeline had talked with the post-doctoral student in her lab and read the articles he had suggested. At the time, she remembered, she didn't understand what she was reading. After weeks of lab work, however, she returned to those articles and found the experience of reading completely different. Interestingly, she described the differences in her understanding in terms of "doing"—what she had recognized in the readings that her lab had done, or could have done: "After working in the lab I can actually understand the papers. Before I could not understand these papers at all. It talks about all these methods and cell lines. It was like a different language for me. And now I recognize these things. Oh, we did this, or oh, we could have done that." Madeline not only understood the terms in the articles she had read, she could see herself, as a scientist, engaging in the activities she described. She saw the human role in the progress of science.

WRITING: A VOICE IN THE CHOIR OF LEARNING

Describing exactly how the physical tasks of the lab translated into greater understanding of the concepts, language, and implications of science is beyond the scope of this article. But Professor Rudek, Madeline's mentor, had no doubt that his mentee Madeline and her cohort would not only learn techniques at the Lab, they would also learn biology: "After ten weeks, their level of biological knowledge has jumped quantum. She'll go back to [her home institution] and when she's sitting in class now, she'll be like, 'I know that, I know that.'" Because I interviewed students at the beginning and near the end of their program, I could see in many of them the transformation of knowledge Rudek described, where not only procedures were clearer, but also the terms of scientific inquiry. Not all students left understanding the full implications of their research. Three months of even embodied laboratory work is not a career; even senior scientists are still learning. As Rose's research on surgeons suggests, however, there is a link between physical activity and conceptual learning:

"Abstractions about physiology or pathology are useless unless embodied" (151). Future research, qualitative and neurological, could explore in greater depth the link between physical activity and conceptual understanding.

Much of what I saw at the Lab should lead us to reassess what activities enhance learning in a laboratory setting, particularly the place of writing in that learning. At the Lab, writing helped structure the various activities, coordinate various participants, serve as a record of what happened, and publicize (locally) the work of each lab. What actually did happen in each lab, however, was most often a form of doing that recruited and developed literacies other than language-based ones. Furthermore, the extended writing assignments students completed—their preliminary reports, their capstone posters, and symposium presentations—promoted different forms of learning (i.e., poster design, generic conventions), rather than duplicating the learning that resulted from repeating manual tasks. In short, writing is one activity that occurs in the lab—not necessarily the key activity. It is a voice in the choir of learning, not the soloist.

"*The extended writing assignments students completed—their preliminary reports, their capstone posters, and symposium presentations—promoted different forms of learning (i.e., poster design, generic conventions), rather than duplicating the learning that resulted from repeating manual tasks. In short, writing is one activity that occurs in the lab—not necessarily the key activity. It is a voice in the choir of learning, not the soloist.*"

Interviews with my student informants suggest that learning for them resulted from a recursive process involving a feedback loop between several kinds of activity: They ran into a problem in data collection, they checked with their post-doc or mentor, they were given some advice, some things to read, a new set-up to look at, a new way to try the experiment. They questioned each other in their REU group meetings, they gave a "chalk talk," they attended a lecture, they applied to a national undergraduate conference, they discussed abstracts, they took photos and videos, they called home to their parents to talk about what kind of scientist they wanted to be. If we group these activities under the heading of "writing," we gloss over many distinct differences in those activities that might be significant to understanding learning across a range of disciplines. Just as significantly, we might fail to maximize collaborations with our colleagues across campus in the instructional programs in which they are the greatest stakeholders.

It should not threaten the progress of writing programs in universities nor the research program of WTL if, when faced with questions from scientists about the centrality of writing to scientific practice, we consider that "they" might be right: writing instruction might not be as necessary to the development of the next generation of scientists as time spent developing physical knowledge, or manual dexterity, or visual acuity in the lab. Indeed, I argue that it would strengthen WTL to understand learning in greater complexity. Writing scholars can take from the Lab's mentors, for example, their appreciation of individual difference in student learning. As we work toward a multi-dimensional model of intelligence, we make more room for appreciating that individuals might learn in different ways, just as they have different habits, preferences, and motivations. One student may "write to learn." Another may not, even within the same discipline. Embracing a more nuanced notion of learning, we might better account for the complex relationships between writing and thinking, student and world.[5]

NOTES

[1] All research was conducted with Institutional Review Board approval. All names are pseudonyms.

[2] The co-director's view of papers and posters as problems echoed the findings of a 1990 National Science Foundation report on REU programs: Faculty mentors interviewed by the NSF felt a summer left no time for ancillary activities, such as working on a joint paper with students (NSF, "Report").

[3] From the Frequently Asked Questions page of the Lab's REU program website: "This program is designed for students that are considering a graduate career (i.e., PhD) in the life sciences. The vast majority of the seminars, training and curriculum are geared for this type of career. Students that are committed to medical school are usually not interested in this type of program and we suggest that you consider NIH sponsored research opportunities."

[4] On the advice of his parents, who wanted Stefan to go to medical school eventually, Stefan declined Kent's invitation.

[5] I would like to acknowledge the generous colleagues who read and gave feedback on earlier versions of this manuscript: Michael Burns, Michael Carter, Anne Haas Dyson, Eileen Lagman, Ligia Mihut, Mya Poe, Vanessa Rouillon and Kate Vieira.

WORKS CITED

Ackerman, John. "The Promise of Writing to Learn." *Written Communication* 10.3 (1993): 334-70. Print.

Bloom, Benjamin S. *Taxonomy of Educational Objectives*. Boston: Allyn and Bacon, 1956. Print.

Bormann, Tobias, Claus Wallesch, and Gerhard Blanken. "'Fragment Errors' in Deep Dysgraphia: Further Support for a Lexical Hypothesis." *Cognitive Neuropsychology* 25.5 (2008): 745–64. Print.

Budson, Andrew E., and Bruce H. Price. "Memory Dysfunction." *New England Journal of Medicine* 352.7 (2005): 692-99. Print.

Carter, Michael. "Ways of Knowing, Doing, and Writing in the Disciplines." *College Composition and Communication* 58.3 (2007): 385-418. Print.

Connelly, Vincent, Julie E. Dockrell, Kirsty Walter, and Sarah Critten. "Predicting the Quality of Composition and Written Language Bursts From Oral Language, Spelling, and Handwriting Skills in Children With and Without Specific Language Impairment." *Written Communication* 29.3 (2012): 278-302. Print.

Eichenbaum, Howard. *The Cognitive Neuroscience of Memory: An Introduction.* 2nd Ed. New York: Oxford UP, 2011. Print.

Emig, Janet. "Writing as a Mode of Learning." *College Composition and Communication* 28.2 (1977): 122-28. Print.

Flaherty, Alice. *The Midnight Disease: The Drive to Write, Writer's Block, and the Creative Brain.* New York: First Mariner Books, 2005. Print.

Fontana, Andrea, and James Frey. "The Interview: From Structured Questions to Negotiated Text." *Handbook of Qualitative Research.* 2nd ed. Eds. Norman Denzin and Yvonne Lincoln. London: Sage Publications, 2000: 645-72. Print.

Goggin, Michael E. "Lab Course Goals: Science or Writing?" *Science* 333.6042 (2011): 524. Print.

Hanauer, David I., Graham F. Hatfull, and Debbie Jacobs-Sera. *Active Assessment: Assessing Scientific Inquiry*. New York: Springer, 2009. Mentoring in Academia and Industry ser. Print.

Latour, Bruno, and Steve Woolgar. *Laboratory Life: The Construction of Scientific Facts.* Princeton: Princeton UP, 1986. Print.

Lerner, Neal. "Laboratory Lessons for Writing and Science." *Written Communication* 24.3 (2007): 191-222. Print.

Lett, James. "Emics and Etics: Notes on the Epistemology of Anthropology." *Emics and Etics: The Insider/Outsider Debate.* Eds. Thomas Headland, Kenneth Pike, and Marvin Harris. Newbury Park: Sage Publications, 1990: 127-42. Frontiers of Anthropology ser. Print.

Moskovitz, Cary, and David Kellogg. "Lab Course Goals: Science or Writing? Response to Michael Goggin." *Science* 333.6042 (2011): 524. Print.

---. "Inquiry-Based Writing in the Laboratory Course." *Science* 332.6032 (2011): 919–20.

National Science Foundation. "Overview of REU Program." National Science Foundation, 2012. Web. 13 July 2012.

---. "Report 90-58. NSF's Research Experience for Undergraduates (REU) Program: An Assessment of the First Three Years." National Science Foundation. May 1990. Web. 13 July 2012.

Reynolds, Julia A., Christopher Thaiss, Wendy Katkin, and Robert J. Thompson Jr. "Writing-to-Learn in Undergraduate Science Education: A Community-Based Conceptually Driven Approach." *CBE Life Sciences Education* 11.1 (2012): 17–25. Print.

Rose, Mike. *The Mind at Work.* New York: Penguin, 2004. Print.

Wenning, Carl. "Levels of Inquiry: Hierarchies of Pedagogical Practices and Inquiry Processes." *Journal of Physics Teacher Education Online* 2.3 (2005): 3–11.

Zachos, Paul. "Pendulum Phenomena and the Assessment of Scientific Inquiry Capabilities." *Science and Education* 13 (2004): 743–56. Print.