Improved retention and recall with a peer reviewed writing assignment

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Introduction

Writing of research papers in undergraduate courses is often used to improve students' written communication skills, promote independent study, and enable the application of newly acquired knowledge. There is also an implicit assumption that writing emphasizes and improves higher-order cognitive skills, though there is little evidence that this is true [1]. An important question is whether these gains are influenced by the structure of the writing assignment itself?

The professional publishing process has been used to structure writing assignments, develop in students an appreciation of peer review, and to enhance the development of cognitive skills [2]. Briefly, undergraduate engineering students can be required to write "review articles" in a format appropriate for journal submission, engage in anonymous graded peer review, and subsequently revise their papers for a final score. Writing review articles is, however, primarily an exercise in accumulating and organizing knowledge.

Often a different approach is taken with graduate students, where the goal is to emphasize analysis and synthesis rather than knowledge. For example, the analysis of raw experimental data has been used as a case-based approach to enforcing higher-order cognitive skills [3]. This approach may not be appropriate, however, for many undergraduate classes. Further, this approach was *not* designed to teach the basics of researching the technical literature, writing in a technical style, or of engaging in peer review; these are often assumed skills of graduate students.

We thus sought to bring elements of this graduate-level approach to undergraduate writing assignments to enforce development of higher-order cognitive skills. Rather than having students write relatively open-ended review articles akin to term papers, we alternatively provided them with the stub of a primary research article that they would have to comprehend and complete. We hypothesized that writing in this manner would enhance their acquisition of cognitive skills and their long-term retention of information. We found that writing does in fact enhance long-term retention and recall of *related* technical information, but that the format of the writing assignment itself has no effect on either retention of knowledge or development of higher cognitive skills.

Intervention

We evaluated the writing assignments in the course Cell and Molecular Biology for Engineers at the University of Virginia. Student teams of 3 (enrollment was 102 2nd year undergraduates) were randomly assigned the task of *either* writing a completely novel review article on a specific, contemporary problem in biomedical engineering, *or* of completing a primary research article based on laboratory data addressing a related problem. In this instance, the topic of the review article was assigned to be "regulation of the cytoskeleton by nitrosylation." The primary article was a completed but as yet unpublished study on the effects of nitric oxide and nitrosylation on actin and its ability to support motility driven by myosin. In the latter case, students were

provided with the detailed methods and the results sections only, and had to research and write the abstract, the introduction, the discussion, and develop one novel figure.

Regardless of article type, students engaged in anonymous graded peer review of each other's papers and revised their manuscripts before scoring. This peer-reviewed writing assignment has been used with various permutations in this course for over ten years, and as part of normal educational practice is exempted from Social and Behavioral Sciences IRB oversight.

At the end of the course (after the written assignment was completed), students were presented with a short, *optional* assessment based upon a strict interpretation of Bloom's taxonomy of educational objectives [4] (see the Appendix). Questions were written with constant reference to the example multiple-choice questions given in Bloom's classic work to accurately assess cognitive function at each of the six levels – Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. The students were informed of the reason for these optional questions. The questions focused on problems and concepts that were common to both types of papers, so should in principle be answerable regardless of the intervention. Because we used an unusually strict and rigorous interpretation of Bloom's taxonomy, it should be noted that at the very highest cognitive level (Evaluation) there was indeed no correct answer; rather, there is one answer that an expert scientist would favor, but any of the provided answers could technically be correct.

The ability of the two groups (those completing primary articles and those writing review articles) to answer questions at different levels of the cognitive domain was analyzed using ANOVA and binary logistic regression. Significance levels are provided in the tables and text.

Results and discussion

As a control, one would expect a positive correlation between cognitive and academic ability. Indeed, the data show that midterm exam scores were significant predictors of cognitive level up to and including analysis. Because the assignments were so different in terms of the approach a student would take in researching and writing, it was important to establish that there was no difference between paper scores between the two groups when controlling for midterm exam scores (academic skill). There was no significant difference between the groups (p=0.28), nor was the paper type predictive of academic achievement in the class. This is consistent with previous work showing that a "writing to learn" approach has no differential impact on student achievement of course goals [5].

For cognitive domains that were assessed by more than one question, the results were pooled such that answering any single question correctly in a cognitive domain resulted in a score of 1, otherwise 0 (logical OR). The two paper types were then compared by univariate ANOVA with paper type as a fixed factor. The results are given in the

Cognitive Domain	Sum of Squares	F	*p*
Knowledge	.013	.275	.601
Comprehension	1.781	10.534	*.002
Application	.015	.060	.806
Analysis	.324	1.490	.225
Synthesis	.440	1.764	.187
Evaluation	.460	1.846	.178

Table 1: ANOVA of student scores in each of Bloom's cognitive domains comparing the two types of written papers – writing a review, versus completing a primary research article. *p<0.05

table 1. Binary logistic regression gave equivalent results to ANOVA in terms of identifying significant factors.

Question	*p*
Knowledge 1	0.29
Knowledge 2	0.36
Application 1	0.51
Application 2	0.15
Analysis 1	*0.07
Analysis 2	0.71

Table 2: ANOVA of student scores on two separate questions each of which addresses the same cognitive domain, comparing the two types of written papers. Note the variability between questions. *p<0.05.

In contrast to academic skill, the type of paper written by a student (primary *versus* review) had no consistent predictive ability for cognitive level. The only exception was for comprehension (*) for which students writing review articles scored higher than those writing primary articles. This is somewhat surprising because the question focused on a common experimental method (the biotin-switch assay) that was, in fact, used in the primary article that was being completed. It was noted, however, that virtually all the review articles written by students included an explanation of the biotin switch technique, while those completing the primary articles took it as given.

This highlights both a potential pitfall of a highly structured writing assignment (in this case, providing students with the core of a primary article), and the difficulties of accurately assessing cognitive skill. When one paper type more than the other forces students into immersive study of specific experimental methods, questions that capitalize on that structured learning will give a biased result. This is emphasized by an analysis of each question separately rather than in aggregate (see table 2). For example, a question at the cognitive level of Analysis that asks students to design an experiment shows a p=0.07 bias in favor of students who completed primary articles. Note that the question focused on an experimental technique that, like the biotin switch assay, was used extensively in the primary article but may not have been covered extensively by the review articles. In contrast, a follow-up question on appropriate controls (also at the level of Analysis) showed no difference between the groups.

This suggests that any hints of cognitive gains resulting from completing one writing task versus the other is the product of focused effort by the student and is not generalizable. Claims have been made that graded peer review of students' writing (which was also part of this exercise) "prompts students to develop higher-order cognitive skills."[6] While we have no control group for this particular intervention, we find no evidence that this or any other element of a single-semester written assignment alters cognitive skill.

Eight months after the end of the writing project we conducted an assessment of information recall to determine if the type of paper written by the student influenced their long-term retention of information. Five questions were selected from among those posed on exams during the semester that were related in topic to the papers students wrote – that is, questions having to do with the cytoskeleton, molecular motors, and nitric oxide. Five additional questions were randomly selected that were not immediately relevant to the papers (e.g. DNA replication, metabolism, cell structure). Each of these questions would be categorized into the cognitive domain of Knowledge. The assessment was delivered using an online tool (*www.questionpress.com*).

There was no significant difference between the groups in students' recall of either topical or general knowledge (see table 3). Regardless of group, however, the retention of topical

knowledge was nearly *double* that of general knowledge (58% versus 31%) – a strongly significant difference ($p \approx 0$ by paired t-test). While this seems intuitive, it stands in contrast to student perceptions. Quoting one respondent,

> "I found the paper to be a valuable experience in that it enhanced my technical writing skills, however, I found it to be an inefficient method to learn about nitrosylation of the cytoskeleton. To this day I cannot tell you much about that topic."

It is obvious from the data, though, that this student perception is not generally correct. Our data are consistent with the work of Nevid and coworkers[7] who found that students perform better on exam questions that are *related* to writing content than on questions that are unrelated. We find that long-term recall of *related* knowledge is likewise enhanced. However, our data stand in contrast to the findings of Dynan and Cate who found that structured writing assignments lead to greater low-order cognitive gains [1]; we found no such gains.

Knowledge domain		Knowledge Recall (mean ± sem)
Topical knowledge	Primary	0.58 ± 0.04
	Review	0.57 ± 0.04
	Total	*0.58 ± 0.04
General knowledge	Primary	0.31 ± 0.03
	Review	0.32 ± 0.05
	Total	*0.31 ± 0.03

Table 3: Retention and recall for general knowledge from the course, versus knowledge related to the paper topic. *$p<0.05$ comparing general to topical knowledge.

We also asked students three questions to gauge how the paper writing experience in the subsequent 8 months changed three specific skills related to technical writing.

1. How has your ability to do **research** (search and understand the technical literature) changed as a result of this paper-writing experience?

2. How has your use of writing **tools** (reference management software, word processor features) changed as a result of this paper-writing experience?

3. How has your ability to **write** a technical document (organization, style) changed as a result of this paper-writing experience?

Scores were collected on a scale of 1 to 10, where 1 indicated a worsening of skill, 10 indicated a gain of skill, and 5 indicated no change. Students reported significant gains in each of the skill sets (see table 4), though least of all in the use of writing tools. There was no difference in these self-reports between the primary and review writing groups.

We conclude that researching and writing technical papers, regardless of format, and engaging in peer review greatly enhances long-term retention of related material, and thus serves a particular pedagogical end. Since students were able to better retain and recall information *related* to the written topic and not just the exact information that they wrote, we hypothesize that the learning gains are the result of the repeated retrieval of information during the writing process, and the construction of "recall cues."[8]

In contrast we find no evidence of a change in cognitive ability or general information recall as a result of engaging in short-term structured or unstructured technical writing assignments.

Beyond cognitive and knowledge gains, the students themselves see the value of these writing projects. Many students have reported both in person and in course evaluations that the exercise was vital to their academic development and their ability to succeed in subsequent semesters. The development not only of writing skills, but the ability to search, read, and comprehend the scientific literature is often neglected in engineering curricula. Quoting one typical free-response:

> "I thought the paper was definitely an enriching experience. However, it was an extremely difficult assignment. Learning the intricate details of nitrosylation and the cytoskeleton while figuring out how to write a professional-style scientific review was quite daunting and took a ton of effort outside of class. However, it was definitely a worthwhile experience - something I would for sure do again."

Skill set	Group	Score (mean ± sem)
Research ability	Primary	8.8 ± 0.3
	Review	8.4 ± 0.3
	Total	8.6 ± 0.2
Tool use	Primary	7.5 ± 0.4
	Review	8.0 ± 0.4
	Total	7.7 ± 0.3
Writing ability	Primary	8.4 ± 0.3
	Review	8.1 ± 0.3
	Total	8.2 ± 0.2

Table 4: Student rankings of how the writing project contributed to development of three fundamental skills. No significant differences were noted between the two paper styles.

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Appendix

The cognitive domain assessment administered to students at the time of their final exam was based on "Bloom's taxonomy." [4] The correct answers to each question are highlighted in **bold** type.

Knowledge

1. *Aside* from nitrosylation, nitric oxide may engage in cell signaling through this intermediate signaling enzyme:
    a. Adenylyl cyclase
    b. Thiordeoxin
    c. Nitric oxide synthase
    d. Protein kinase G
2. S-nitrosylation is
    a. The nitrosative modification of a metal
    b. The covalent addition of a NO group to a thiol
    c. The modification of tyrosine to yield nitrotyrosine

Comprehension

3. You want to determine whether or not a given protein is nitrosylated. The appropriate experimental technique for making this determination is:
    a. Biotin switch
    b. Laser trap
    c. Motility assay
    d. ATPase assay

Application

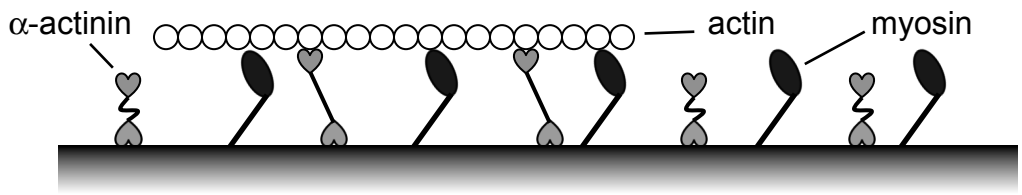
4. Nogueira and coworkers measured the effects of nitric oxide donors on the actin-activated ATPase rate of myosin and found that treatment with nitroso-glutathione decreased the ATPase rate of myosin compared to control by about 30%. What can you conclude about the molecular effects of this donor on myosin?
    a. The time myosin spends attached to actin increases.
    b. The time myosin spends detached from actin increases.
    c. The time increases between when myosin binds one ATP and when it binds the next ATP.

5. Myosin-binding Protein C is an important regulatory protein found in heart muscle. Mutations in this protein can cause disease. It contains 21 cysteines, and when exposed *in vitro* to NO-donors it becomes heavily nitrosylated. What can you conclude from this information?
    a. Nitrosylation of myosin-binding protein C will cause heart disease.

b. The function of myosin-binding protein C is regulated by nitrosylation.
c. Myosin-binding protein C may itself serve as an endogenous NO-donor in heart muscle cells.

Analysis

6. The actin-binding protein α-actinin is readily nitrosylated by donors of NO, so we hypothesized that nitrosylation affects α-actinin's ability to bind actin. We performed the following experiment to test this hypothesis.



We conducted a motility assay with actin (white spheres) running over myosin (black) on a coverslip (shaded) that is also coated with α-actinin (gray). It is already been shown that as actin is propelled by myosin, α-actinin binds to and exerts a drag on the actin filament, slowing it down.
Our intent was to use the degree of slowing as a measure of the strength of the α-actinin bond with actin.

In order to test our hypothesis that nitrosylation of α-actinin changes its ability to bind to actin, we should load proteins and donors into the flow cell in the of the following order, from first to last:

a. myosin – α-actinin – actin – NO-donor
b. α-actinin – myosin – actin – NO-donor
c. myosin – α-actinin – NO-donor – actin
d. α-actinin – NO-donor – myosin – actin
e. none of these is a valid approach

7. Regardless of the sequence above, a *necessary* control for the interpretation of your results which of the following?
   a. Omit the NO-donor
   b. Omit the α-actinin
   c. Omit both the myosin and the NO-donor
   d. Omit both the NO-donor and the α-actinin
   e. In separate controls omit the NO-donor, the α-actinin, and both the NO-donor and the α-actinin.

Synthesis

8. In striated muscles, the proteins tropomyosin and troponin render actin filaments sensitive to calcium. Consider the following three experimental results.

   According to a study by Skórzewski and coworkers in 2009, *removal* of the last three amino acids of actin, which includes cys-374, decreases binding of tropomyosin to actin, and causes the tropomyosin to shift to a "more active state" on actin, meaning that myosin binding and ATPase activity is higher than control.

   Dalle-Donne found that actin cys-374 can be nitrosylated.

   Several groups (for example, Perkins and coworkers) have found that NO-donor treatment of muscle myofibrils, which contain *only* and *all* of the contractile proteins of muscle, causes the calcium sensitivity of the system and the ATPase rate of the myosin to be lower than control.

   Based on these three observations alone, which of the following is a logical hypothesis to pose that would guide further experiments?

   "The reduction in calcium sensitivity and actin-activated ATPase brought about in muscle by nitric oxide…"

   a. … can be explained by the nitrosylation of actin and myosin alone.
   b. … must be the result of nitrosylation of at least one other myofibrillar protein.
   c. … can be fully explained by nitrosylation of actin alone.
   d. … cannot be explained by the nitrosylation of either actin nor myosin, and therefore must be the result of at least one other myofibrillar protein.

Evaluation

9. Nogueira and coworkers used two different nitric oxide donors to treat myosin – one endogenous (nitroso-glutathione) and one synthetic (NONOate). Likewise, Evangelista and coworkers used two different nitric oxide donors to treat myosin – a different endogenous donor (nitroso-cysteine) but the same synthetic donor (NONOate). NONOate is a donor of free (gaseous) NO.

   Nogueira reported that while the endogenous donor reduced the ATPase rate of myosin, NONOate did not. Evangelista reported that both the endogenous donor and NONOate slowed actin filament velocities in motility assays.

   Which of the following hypotheses *best* accounts for all these data and is most consistent with what is generally known or accepted about nitrosylation?

   a. Nitroso-glutathione binds stereospecifically to a different site on myosin than does nitroso-cysteine. Free NO reacts either with a third site, or with only one of these two sites.

b. **The two different endogenous donors nitrosylated identical sites on myosin in each of the studies. Likewise, free NO nitrosylated identical sites on myosin in each of the studies. However, the site nitrosylated by free NO and the site nitrosylated by endogenous donors were different. The apparent discrepancies between the two studies when using endogenous donors are explained by the fact that ATPase assays and motility assays do not measure the same parameters.**
c. The Nogueira study used full-length myosin, while the Evangelista study used a myosin fragment – HMM. Nitroso-glutathione nitrosylates and affects the function of the tail of myosin, while nitroso-cysteine nitrosylates and affects the function of the head. Free NO also nitrosylates the head.