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Writing-To-Teach: A New Pedagogical Approach To Elicit Explanative Writing from Undergraduate Chemistry Students

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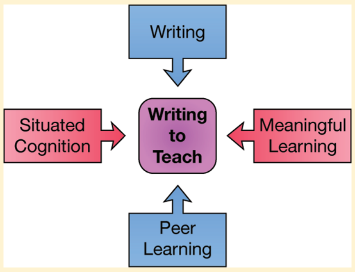
S *Supporting Information*



ABSTRACT: Contemporary strategies in STEM education focus on developing pedagogies that more actively engage students in their own learning. A method that has proven effective to this end has been peer instruction and discussion, particularly those in which participating students must organize information in such a way as to be able to verbally articulate it to others. The success of peer learning raises the question of what other communicative activities could lead to similar learning gains. Writing is a reasonable choice for such an activity, as there is strong historical evidence of the value of writing in facilitating student learning. Presented here is "writing-to-teach"; a fusion of writing and peer instruction that is rooted in the theories of meaningful learning and situated cognition as well as research on student-generated explanatory knowledge. Writing-to-teach activities were designed and implemented in an introductory physical chemistry course and evaluated using student surveys. In addition, a novel expert-ranking methodology was employed to evaluate the quality of explanatory writing produced by students engaging in writing-to-teach activities. Lastly, suggestions are given on how writing-to-teach can be implemented more broadly in other STEM classrooms.

KEYWORDS: *Second-Year Undergraduate, Curriculum, Physical Chemistry, Collaborative/Cooperative Learning, Communication/Writing, Quantum Chemistry, Student-Centered Learning*

Students are rarely prompted to construct explanations of scientific phenomena for themselves.[1] In many undergraduate science courses, students spend a great deal of time either passively listening to lecturers' explanations or reading explanations from textbooks. Moreover, textbook explanations are often presented succinctly and in rapid succession, as if the material is straightforward and requires nothing more than memorization. Classroom activities that facilitate students generating their own explanations (i.e., developing and deploying explanatory knowledge) can therefore be powerful conceptual teaching and learning tools. Active learning strategies such as cooperative learning groups,[2−6] guided inquiry,[7,8] and peer-led team learning[9−11] demonstrate progress toward student production of explanations in the undergraduate chemistry classroom. Of particular note are peer-to-peer communication activities, such as *concept tests*, which are questions woven into lectures that offer students the opportunity to discuss their understanding of concepts and learn from each other's explanations.[12] Though undergraduates are certainly not "experts", students who have just grasped a concept may be able to explain it to a classmate more effectively than an instructor for at least three possible reasons.[13] First, the insight is fresher. For example, if an instructor learned a fundamental chemistry concept some time ago, the instructor may forget whatever obstacles there were to initially mastering the idea. That is to say, in cases for which the concept was "obvious" to the instructor, it can be difficult for the instructor to have an appreciation for why it may not be obvious to someone else. Second, classmates often speak a more common jargon that better facilitates communication. Years of constructing polished explanations can leave an instructor disconnected with regard to cultivating an appropriate explanation for students. Third, the instructor is an authority figure; this presents a barrier for some students in terms of establishing a level of comfort suitable for learning directly from the instructor. Regardless of how peer interactions are implemented, they are understood to play an important role in improving learning, as peer discussions help students make connections between new knowledge and prior knowledge, validate new knowledge, and foster a sense of community.[14−17] The success of concept tests in facilitating peer teaching and learning through student-generated explanations raises two questions that frame the current study: (1) Can *writing* be used to facilitate peer teaching and learning (i.e., allow students to straightforwardly produce quality explanations)? and (2) Will students perceive peer teaching and learning via writing to be a valuable learning activity?

■ EXPLANATORY VERSUS SUMMARY WRITING

Writing has long been understood to be an important pedagogical tool to improve discipline-specific writing skills

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and understanding. Writing has been shown to help learners organize and reconstruct existing knowledge so they can then connect new knowledge with previous knowledge.[17,18] In science courses specifically, writing has been associated with improved critical thinking and an improved ability to synthesize information.[16,19−24] Writing also has a long history of being employed as an active learning strategy in the chemistry classroom and teaching laboratory.[16,18−21,24−30]

It is important to distinguish among different types of writing and to determine whether these types can be tailored to reinforce specific learning goals. Previous work demonstrates a profound pedagogical distinction between writing *summaries* and writing *explanations*.[31] Often in classroom settings, students engage in summary writing; that is, they simply provide synopses of material because they assume the reader, the instructor, is already an expert in the subject matter. In explanatory writing, however, students must clarify how and why phenomena occur[32] to audiences other than the instructor. Unlike writing summaries, generating explanations requires students to reconstruct information and integrate this information with prior knowledge. In a laboratory study, Coleman, et al. investigated the effect of students generating explanations versus summaries on specific learning outcomes.[31] Both students directed to summarize a text and those directed to explain a text performed similarly on near-transfer tasks. However, students directed to explain the text performed better on far-transfer tasks. The authors argue that preparing explanations requires superior knowledge integration, which positively influenced students' ability to carry out far-transfer tasks. Further, students who prepared to teach their peers consistently outperformed other students on all tasks. It is argued that preparing to teach engages students more deeply with material (i.e., the act improves active processing and inference making), as teaching requires the reorganization of information to best suit the teaching context.[31,33]

According to Hounsell,[34,35] students have different conceptions of the purpose of writing and these conceptions impact the approaches used by students when writing. For example, students who conceive of writing assignments as exercises in arranging facts tend to use writing as a means of reproducing, restating, or regurgitating ideas collected from a number of sources. In contrast, students who conceive of writing as a process of creating an argument tend to use the writing experience as a means of engaging with content to make meaning. Work by Prosser and Web[36] links this relationship between conception and approach to the *quality* of writing produced, as indicated by linguistic analyses focusing on essay structure and the presentation of content. Simply put, students who conceive of writing as collecting points or facts tend to produce lower quality writing, while students who conceive of writing as creating an argument tend to produce higher quality writing.

A clear conjecture emerges from these prior works—writing activities that engage students in generating explanations lead not only to greater learning gains but also to higher quality writing. Conversely, writing activities that promote summarizing or "fact arranging" lead to diminished learning gains and low quality writing. To date, the literature is silent on whether typical writing assignments in STEM courses tend to promote summary or explanatory writing. A 2008 study by Reynolds and Moskovitz[37] that analyzed the underlying pedagogies of science writing activities does, however, lend insight. The authors examined a large library of writing assignments associated with the Calibrated Peer Review (CPR) program, and found that only 47−67% of assignments within the CPR database are designed to promote critical thinking and less than a third promote the development of higher-order writing skills. Thus, designing methods by which science writing assignments can explicitly elicit explanations from students is imperative to transform writing into a more effective pedagogical tool.

■ THEORETICAL FRAMEWORK FOR WRITING-TO-TEACH

We propose "writing-to-teach", a combination of writing and peer learning, as a method to transform standard science writing assignments into those that allow students to straightforwardly engage in explanative writing. In writing-to-teach activities, students create learning resources for their peers. During this process, students confront, remediate, and reorganize their own knowledge in ways that impact the learning of others. As this act is no different than the act of teaching, constructing and disseminating written explanations could potentially have a great deal of pedagogical value for both the peer author and peer learner.

Our theoretical framework for writing-to-teach is informed by the theories of situated cognition[38,39] and meaningful learning,[40] both of which place high value on engaging students in authentic and meaningful learning activities. *Situated cognition* is suitable to ground a combination of peer learning and writing because, as Lave argues,[41] learning occurs as a function of the activity, context, and the culture in which it occurs (i.e., learning is "situated"). Research in situated cognition tends to focus on how people learn while involved in authentic, meaningful activities, such as apprenticeships, collaboration, and reflection.[39] Thus, the act of teaching can be used to transform writing into an activity that is more meaningful to the learner. *Meaningful learning,* according to Ausubel and Novak, requires a set of three conditions. First, the student must have some set of prior knowledge upon which to build new understanding. Second, new material being presented to the student must be relatable to the student's prior knowledge. If new material is too far removed from the student's prior knowledge, he or she will have no foundation upon which to build an understanding of the new material. Third, the student must choose to make and build connections between prior knowledge and new knowledge. Without the student's active participation in developing a new understanding, he or she cannot engage in meaningful learning.[40,42] Practically, for meaningful learning to occur, students must engage in material that can be clearly related to prior knowledge via learning activities that are designed to encourage students to make these connections. This of course necessitates students and instructors working *together* to build said connections and consequently, new meaning (i.e., shared meaning must be attained).[40,42,43]

It follows that meaningful learning can be achieved by situating instructional activities in contexts that (1) are authentic and meaningful to students and (2) encourage connections with prior knowledge and the building of shared meaning. Writing-to-teach meets both of these criteria. This method is also well aligned to Gopen and Swan's assertion that achieving clarity in writing when using information to express meaning is contingent upon attending to the needs of a particular audience.[44] Here, the design and implementation of writing-to-teach activities in an introductory physical chemistry course is detailed. An evaluation of these activities is also presented.

IMPLEMENTATION OF WRITING-TO-TEACH ACTIVITIES

Writing-to-teach activities were implemented in a one-semester introductory physical chemistry course at a large midwestern research-intensive university. This course, which serves as a second-year course in the university's chemistry-major sequence, covers the traditional topics of physical chemistry, including quantum mechanics, thermodynamics, equilibrium, and kinetics. This course builds on a phenomenological understanding of chemical structure and reactivity gained from a first-year organic chemistry sequence described elsewhere[45,46] and aims to introduce students conceptually to the physical principles of chemistry.

This course was chosen as an appropriate course to implement writing-to-teach for several reasons. First, unlike first-year students, students enrolled in this course have taken at least one year of college chemistry. Therefore, students have a good deal of chemistry knowledge upon which to build when engaging in writing-to-teach activities. Further, there is documented research showing that many students begin a course in physical chemistry with negative perceptions and attitudes.[47,48] Much of this negative perception is attributed to a perceived imbalance favoring mathematical reasoning over conceptual understanding in a traditional physical chemistry course. Improving students' ability to explain concepts of physical chemistry through writing-to-teach in an introductory course may act to improve perceptions of the discipline. Lastly, this introductory physical chemistry course is unique to this university's chemistry curriculum, in which students begin with an organic chemistry course rather than a traditional general chemistry course. Because this course is unlike most traditional physical chemistry courses, appropriate learning materials are not readily available. Therefore, the products of the writing-to-teach activities could be used to supplement existing course materials once a library of resources that could support the entire course has been developed.

Writing-to-teach activities were implemented in a studio environment outside of regular class time. By "studio" we mean to borrow pedagogical terminology from those in the arts, where a *studio* is a setting where artists share their creations (a composition, a painting, a dance, a sculpture, etc.) and obtain feedback so as to refine those creations. This model has been applied to the chemistry classroom with success.[49−51] These implementations (in particular, the "structured study group" model[51]) influenced our decision to offer the writing-to-teach studio as a supplemental "honors" option in which studio students met for an additional 2 h per week throughout the entire semester to engage in writing-to-teach activities. In the writing-to-teach studio, students worked in small groups to develop a supplemental text for the quantum mechanics section of the course. Quantum mechanics was chosen because it was the first topic covered in the course and because quantum mechanics is traditionally a difficult topic to grasp conceptually. For each topic within quantum mechanics (Table 1), teams of students worked on one of three traditional sections of a textbook: the text section, a literature-based or "real-world" illustrative example, and a set of practice problems with annotated solutions. Prescriptive outlines (composed of guiding questions and recommended literature sources) were used to direct student work for each type of writing-to-teach activity. Peer leaders, undergraduates who had successfully completed the course and helped to design the prescriptive outlines, led the studio sessions. The role of the peer leaders here was not to teach new content to the students. Rather, peer leaders were expected to guide writing-to-teach activities and help the students remain focused on these activities during studio time. Studio activities included researching and planning, peer reviewing, and writing and revising. In particular, peer reviewing was an essential component to this writing-to-teach implementation and focused heavily on a writing sample's utility as a teaching device. In the language of the theoretical framework presented above, the peer review process was one way by which writing activities were grounded in the act of teaching (i.e., authenticated). For further details of the writing-to-teach studio organization and activities, please refer to section S1 of the Supporting Information.

Table 1. Topics for Writing-To-Teach Activities in Introductory Physical Chemistry

Text or Problem Sections	Illustrative Examples
The failures of classical physics	Atomic line spectra
Wave−particle duality and Heisenberg's principle[a]	Diffraction experiments[a]
Waves and wave functions	Sonar
Postulates of quantum mechanics	Schrödinger's cat
Schrödinger's equation and particle-in-a-box[a]	Absorbance spectra of β-carotene and lycopene[a]
The harmonic oscillator	Living in a quantized world
The quantum mechanical atom	Neon lights
Interpreting atomic wave functions	Hydrogen atom emission spectrum

[a] Examples of prescriptive outlines for this topic are included in the Supporting Information (examples S1−S4).

METHODS OF ASSESSMENT

Approximately 16% of the introductory physical chemistry course enrollment (18 students) opted to participate in the pilot writing-to-teach studio. All studio students participated in the following assessments, unless otherwise noted. Because students self-selected into the studio, diversity in gender (4 females, 14 males) and ethnicity (9 white or Caucasian, 8 Asian-American, and one student from an underrepresented STEM population) were not examined in the following analyses. Institutional Review Board (IRB) approval was sought and the study was determined to be exempt from IRB oversight because the experimental design was in keeping with normal classroom practices.

Expert Ranking of Written Exam Responses

The first research question framing this study probes the effectiveness of this writing-to-teach implementation. We anticipated that any influence of writing-to-teach on students' ability to generate explanations would not be reflected in measures of course performance, as the majority of exam items were not designed with this learning goal in mind. Moreover, the means of relevant exam scores for the writing-to-teach students and the nonstudio students are virtually noncomparable due to the low power of the necessary t test (section S2, Supporting Information). Thus, it was necessary to craft an assessment method specifically aligned to the goal of heightening students' ability to craft explanations.[52] To assess the quality of explanations generated by writing-to-teach students in comparison to nonstudio students, two extended written response test items from the course's first exam were analyzed in depth (methodology described below). These exam items were chosen because they were the only extended-response items of any course assessment whose foci overlapped with the content of the writing-to-teach studio. Therefore, only in these assessment items would one expect a heightened ability to explain a quantum mechanics concept (as was hypothesized for the studio students) to be displayed.

The following extended-response items from the first course exam were used in this assessment:

(1) Describe an experiment that demonstrates the wave-like properties of electrons. Discuss the observation and why it requires describing electrons as waves.
(2) Describe an experiment that demonstrates the particle-like properties of light. Discuss the observation and why it requires describing light as a particle.

Only responses determined to have equivalent content were selected for analysis. Responses to both items from all 110 students in the course were coded for content using an instructor-generated rubric. All student responses to the first item used in this analysis presented Young's double-slit experiment as evidence, correctly described this experiment's result, and used the concept of diffraction to explain why this experiment suggests wave-like properties for electrons. All responses to the second item used in this analysis employed the photoelectric effect as evidence, correctly described this phenomenon, and used the concept of threshold frequency to explain why this phenomenon suggests quantized, particle-like properties for light. Overall, 16 samples from writing-to-teach students and 24 samples from nonstudio students were chosen for analysis.

It was expected that experts in the field would be attuned to subtle differences in explanation quality between writing-to-teach and nonstudio students that could not be detected when looking solely at the content displayed in a single response. Writing samples selected for analysis were transcribed to typeface, and all accompanying illustrations (if applicable) were scanned and added to the transcribed text. Samples from writing-to-teach and nonstudio students were grouped in triplicate. Each group of three writing samples consisted of responses to the same exam item and contained a mix of writing-to-teach and nonstudio students. For example, one grouping might contain two responses from writing-to-teach students and one from a nonstudio student, whereas another might contain two responses from nonstudio students and one from a writing-to-teach student. Groups of responses were distributed to experts (physical chemistry faculty, graduate students, and postdoctoral fellows) who were asked to rank the three responses in each group based on the overall quality and clarity of explanation (1 = best, 3 = worst). Each expert received more than one group of responses to ensure that all responses included in the analysis were ranked a relatively equal number of times. Responses from the writing-to-teach students were ranked a total of 84 times, whereas responses from the nonstudio students were ranked 82 times. Groupings were also configured such that most writing samples were evenly distributed among 2:1 and 1:2 (studio/nonstudio) combinations.

Student Attitudes Survey

The second question framing this study probes student perceptions of writing-to-teach and the manner in which the methodology was implemented. To gain insight into this question, an attitudes survey was administered to all writing-to-teach students at the conclusion of studio activities. The survey consisted of 27 Likert scale and 4 free-response items. The Likert scale items explored both student perceptions of their learning gains as well as opinions of the writing-to-teach implementation strategy. The Likert scale statements and free-response items are reported in the Supporting Information (Table S1 and Table S2, respectively). Glaser's method of grounded theory analysis[53] was applied to extract common themes from student responses and the results of this analysis are presented in below.

■ RESULTS AND DISCUSSION

In an assessment of student writing on short-answer exam items by experts, it was found that students who participated in writing-to-teach activities were judged to write better explanations of their understanding of course material. A histogram of expert rankings of writing-to-teach and nonstudio student exam responses is presented in Figure 1. This histogram combines the rankings for both exam items detailed in the Methods of Assessment section. Data are presented on the ordinate as the fraction of students, expressed as percent, whose responses where rated by experts as either "1" (best), "2", or "3" (worst) (presented on the abscissa). For example, 46% of the responses composed by writing-to-teach students were ranked *at least once* as 1 by an expert, while only 20% of the responses composed by nonstudio students were ranked at least once as 1 by an expert. Conversely, 45% of the responses composed by nonstudio students were ranked as 3 by an expert. Examples of responses consistently ranked as 1 and as 3 are included in the Supporting Information (Sections S3 and S4). Thus, responses from writing-to-teach students were rated as better explanations more frequently than responses from nonstudio students, even though content was consistent across all writing samples. This result serves as strong evidence that writing-to-teach activities heightened students' ability to construct explanations. However, a plausible alternative explanation of this result is that student self-selection into the writing-to-teach studio gave rise to an experimental group composed of disproportionately better writers. Although data concerning previous experiences with writing were collected for writing-to-teach students, no such data were collected for

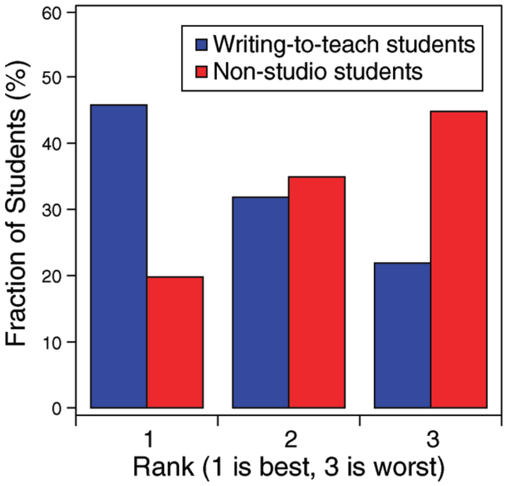

Figure 1. Expert rankings of written exam item responses. The *y* axis indicates the fraction of students whose responses where rated by experts as either "1" (best), "2", or "3" (worst).

nonstudio students. Thus, due to limitations of the current data, this alternative explanation cannot be conclusively ruled out.

Upon further examination of the exam item responses, it was observed that writing-to-teach students were more likely to use nontextual representations to supplement responses. Fifty-seven percent of samples from writing-to-teach students contained figures whereas only 30% of samples from nonstudio students contained figures. There was no correlation between expert ranking and use of illustrations, as only 34% of responses ranked as 1 used figures. Thus, experts were not likely inferring a stronger explanation from the use of an illustration. Intriguingly, however, 53% of the writing-to-teach samples ranked as 1 used figures whereas none of the nonstudio samples ranked as 1 used figures. In writing-to-teach activities, students were encouraged to utilize multiple modalities, including illustrations, in crafting their textbook sections. It is plausible that writing-to-teach students perceived the use of illustrations to complement text sections as a way to enhance the text's efficacy as a teaching tool. Thus, the writing-to-teach students were more apt to utilize multiple modalities when crafting explanations in response to exam items.

An end-of-term survey revealed that students reacted positively toward writing-to-teach methods, and felt that the activities enhanced their learning (Table 2). Of note is the insignificant difference between the responses to statements 1 and 2. The former statement solicited student attitudes concerning writing-to-learn in general, whereas the latter statement probed the act of writing-to-teach. The positive response to the latter statement demonstrates that the majority of students believed the teaching (explanatory) aspect of these writing activities was just as beneficial to learning as the act of writing itself. Granted, that a small group of students who voluntarily worked together for a semester found these experiences valuable is not unexpected. However, responses to statements 3 and 4 suggest that students not only valued writing-to-teach activities, but also valued them *more so* than other traditional learning activities.

Table 2. Selected Attitudes Survey Questions and Aggregate Responses

Statement	Mean[a]	SD
1. I believe writing can be an effective way to learn chemistry.	1.94	1.14
2. I felt that by writing to teach others, I was able to learn the material better myself.	1.71	0.85
3. I felt that taking part in the [writing-to-teach] studio heightened my overall understanding of quantum mechanics.	1.65	0.79
4. I felt that taking part in the [writing-to-teach] studio was more helpful in learning quantum mechanics than other nongraded activities offered in [this course] (lectures, reading, etc.)	2.06	0.97
5. I felt that taking part in the [writing-to-teach] studio prepared me for [this course's] midterm and final exams.	3.00	1.12

[a] For these questions, students were prompted to "strongly agree" (1), "agree" (2), remain neutral (3), "disagree" (4), or "strongly disagree" (5). Mean responses to all questions comprising this survey are reported in the Supporting Information (Table S1).

A grounded theory analysis of student responses to free-response survey items revealed three main themes; these themes and examples of supporting student statements are presented in Table 3. The theme of the benefit of active learning emerged from this analysis, supported by 10 comments regarding the benefits of actively engaging with the material in the writing-to-teach studio. A second theme emerged concerning the effect of writing for the purpose of teaching others. Eleven supporting statements and no specific negative comments about this aspect of the writing activities were found, suggesting that students recognized the difference between the explanatory writing-to-teach activities and other types of writing, such as descriptive or summary writing. Students also expressed that they gained a solid conceptual understanding of quantum mechanics. However, some students also noted that while they deepened their understanding of quantum mechanics, this increased understanding did not translate to an enhanced course performance. A total of 12 statements expressing an increased conceptual understanding of quantum mechanics as a result of the writing-to-teach studio were found. Of those 12 statements, five also expressed that their increased conceptual understanding did not help them in the overall course. These students recognized a disconnect between the goals of the writing-to-teach studio and the goals of the general course. This result is mirrored by the somewhat more negative response to statement 5 in Table 2. As mentioned above, while the goal of the studio was to improve the students' conceptual understanding and written explanations of quantum mechanics, course assessments were not designed to discern deepened conceptual understanding from a cursory understanding or simple rote learning.

■ SUMMARY

A novel pedagogical strategy, "writing-to-teach," was developed to incorporate the benefits of peer learning and explanatory writing. This strategy was incorporated into a second-year introductory physical chemistry course as a supplemental peer-led studio session. Two research questions guided our evaluation of this methodology: (1) Will writing-to-teach activities heighten students' ability to produce explanations? and (2) Will students perceive writing-to-teach activities to be a valuable to their learning? Two assessment methods were chosen to answer these questions: a novel analysis of written exam item responses and a student attitudes survey, respectively. Selected extended exam responses of writing-to-teach and nonstudio students were ranked by experts using

Table 3. Emergent Themes from the Analysis of Student Free-Responses

Theme	Representative Student Statement
Benefit of active learning	*Having students participate more actively in writing about a topic rather than just reading a textbook can be very effective for learning difficult topics such as quantum mechanics.*
Writing for the purpose of teaching others	*I've always liked teaching others and feel that it enhances my learning. Being able to write from a perspective of teaching has further solidified these feelings.*
Increased conceptual understanding of quantum mechanics, but disconnect with course	*I feel like [writing-to-teach studio] didn't help that much for the... class. However, it did help me a lot in learning about quantum mechanics. It helped me learn about the general idea of quantum mechanics but not about the things that were going to be tested on.*

quality of explanation as the ranking criterion. Responses from writing-to-teach students were consistently ranked higher than those of nonstudio students in this analysis, even though all responses were coded to have similar content knowledge prior to the expert ranking. This result suggests that writing-to-teach activities improved students' ability to generate explanations. Survey data indicate that students recognized the benefit of writing-to-teach activities and felt that they gained a greater understanding of quantum mechanics from the activities. However, many students noted a disparity between the writing-to-teach studio activities and the course assessments, mentioning that while they learned a lot about quantum mechanics, the activities did not help them in the course in general. This student observation—that engaging in studio activities did not result in heightened course performance—was not unexpected. The supplemental writing-to-teach studio was designed to elicit gains in conceptual understanding and explanation generation, learning goals on which typical course assessments are relatively silent. By employing an assessment strategy that was aligned with pedagogical intent, we have shown here that writing-to-teach activities implemented in a studio environment likely enhance students' ability to generate explanations.

■ REVISED IMPLEMENTATION OF THE WRITING-TO-TEACH STUDIO

Implementation of writing-to-teach activities is a continuing project and many changes have been made since the pilot version of the studio environment reported here. On the basis of student feedback in surveys and focus group sessions, the original writing-to-teach activities (text, illustrative example, and worked problems) have been altered. Most students from the first cohort felt the "illustrative example" and text assignments were the most beneficial to their learning (Table S1, Supporting Information). As a result, all studio student students currently write expanded contextualized examples, in which a quantum mechanics concept is explained within the context of a real-world or experimental example (called "explorations"). This change is also more congruent with the theoretical framework informing writing-to-teach, as these revised assignments should more easily allow students to engage in meaningful learning. For further changes to the organization of the writing-to-teach studio, please refer to Section S5 of the Supporting Information.

■ BROADER IMPLEMENTATION STRATEGIES FOR WRITING-TO-TEACH

The theoretical and evidence bases for a new pedagogical device—writing-to-teach—were presented. The implementation strategy presented (studio learning environment) was the result of adopting the tenets of writing-to-teach (peer teaching and learning, writing, situated cognition, meaningful learning) specifically to meet the needs and constraints of the introductory physical chemistry course. In different courses under different circumstances, we can envision many implementation possibilities. For example, the writing-to-teach methodology could be adopted by a large lecture general chemistry course by asking students to explain chemical phenomena as if they were teaching a peer. Theoretically, as long as the activity remains authentically and meaningfully situated in the act of teaching (perhaps by devoting a portion of the assignment's evaluation to its utility as learning material, thereby abating the disconnect between the goals of writing-to-teach and traditional course performance goals), students should generate explanations of a higher quality than when the teaching situation is absent. When coupled with software such as Calibrated Peer Review (CPR),[54,55] which permits writing assignments to be easily introduced into a large lecture classroom environment and can introduce a peer-review process to further ground the activities in the act of teaching, writing-to-teach can be used to engage many more students than in the implementation presented here.

Writing-to-teach can also be easily implemented in laboratory courses by, for example, requiring students to explain experiments and experimental results to the general public. In a recent contribution by Moskovitz and Kellogg,[56] the authors argue that recent reforms to writing in science laboratory courses can be classified as either "writing-to-learn" (WTL) or "writing-as-professionalization" (WAP). In WTL approaches, such as the Science Writing Heuristic, writing activities prompt students to engage with the scientific process and reflect more deeply on the underlying scientific principles than do traditional lab reports.[16,57] In contrast, the WAP approach prompts students to generate professional artifacts such as poster presentations and standard research reports.[58,59] We contend that implementing writing-to-teach in the chemistry laboratory takes on characteristics of both WTL and WAP and closely approximates an ideal proposed by Moskovitz and Kellog—"inquiry-based writing". This is true for three reasons. First, writing-to-teach (in this case, explaining scientific results to a general audience) is a form of writing that working scientists use. Second, the writing activity is aligned with the lab activity (i.e., the student is generating and explaining or discussing results of a real scientific experiment). Third, the student is writing to a defined audience other than the instructor. In addition, the assessment element of a writing-to-teach laboratory implementation would be consistent with this notion of inquiry-based writing, as students would not be completely assessed on claims that match expected outcomes. Rather, students would be assessed on how clearly and convincingly each argument is made and how well their writing is able to teach or inform others.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Descriptions of the writing-to-teach studio organizations in the initial and revised implementations; statistical comparison of exam scores for studio and nonstudio students; complete student attitudes survey and associated aggregate response data for Likert-type questions; examples of prescriptive outlines for writing-to-teach assignments (text sections, illustrative examples, and worked problems); examples of student responses consistently ranked as "1" or "3" by experts. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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