

## **Writing to Improve Conceptual Understanding in STEM Disciplines Abstract**

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Educators know that writing promotes knowledge retention. When applied in the context of critical inquiry, writing provides multiple opportunities for students to participate in the disciplinary discourse and forwards the development of literacy skills. Key to this process is stimulating the discourse. This study investigates the connections between research writing in English composition and conceptual understanding in an online physics course. The process of integrating curriculums in composition and physics required monitoring the integrity of both courses while finding ways to compliment the established learning outcomes. This paper is a discussion of the development of strategies for designing, teaching, and integrating writing as a part of the thinking process students undergo when learning science. The results from this integrated meta-course research have the potential to shape the future development of writing and science courses which share cross-disciplinary approaches to teaching and learning.

### **Introduction**

English composition has long been established as a core component to jumpstart freshman students' critical thinking through writing. At a time when a strong emphasis is being placed on science, technology, engineering, and math (STEM) education, it is critical that curricula is developed to strengthen and encourage the link between freshman writing and these disciplines. Science education research suggests that active learning is paramount to student success as critical thinkers and learners. Successful students make connections between writing and critical inquiry (Langer 90). It stands to reason then, that writing for conceptual understanding of the content will promote that success. While many institutions incorporate a writing component into their science curricula, few have a coordinated collaborative effort to fully integrate composition and science disciplines. Our goal to meet this need, led us to create an

online linked meta-course which integrated a research-based English composition course and an energy-based physics course. The result was a pilot study intended to measure students' abilities to construct scientific knowledge based on their abilities to articulate these concepts via writing.

### **English Instructor**

Successful internalization of challenging concepts like motion, potential energy, and entropy, often hinges on a student's ability to conceptualize them in multiple ways – visual, written, and oral mediums – to develop a scientific literacy. By internalizing complex issues from multiple perspectives students' understanding is often increased. Physics education research has pursued multiple empirical investigations on the link between what students think and their ability to explain how they come to some determination (McDermott and Redish). Such an exhaustive research agenda within the discipline surely indicates a common belief among physicists that there is room for improvement between students' "thinking" and "doing."

Arons offers that "research is showing that didactic exposition of abstract ideas and lines of reasoning (however engaging and lucid we might try to make them) to passive listeners yields pathetically thin results in learning and understanding" (vii). The research has also determined that "students' knowledge of physics consists of many discrete facts and formulas only loosely connected to each other" (Knight 25). One goal of writing instruction is to teach students to contextualize and organize information into a coherent framework, thereby applying that information in similar contexts across multiple disciplines (Carroll). Hopp suggests that requiring students to write about the physics phenomena they observe leads them to "use those experiences to expand their understanding" (445).

Similarly, distance education research reveals that virtual tools are stimulating students in ways that cannot happen in the conventional classroom (Bothun, Mohottala, and Sipe). As an educational medium, the online classroom moves the students from passive audience to active learners and contributors. Students in online courses cannot expect their "smart" peers to carry the classroom conversation. Without the physical presence of a conventional lecturer, the instructor can facilitate interactive engagement among the entire learning community. Physics education research confirms that instructors who use this type of social learning, "show much higher conceptual learning gains than those that rely exclusively on passive lecture methods" (Goldberg, Otero, and Robinson

1266). Stanford-Bowers confirms that “An ideal online learning environment is highly interactive with all participants consistently involved with content, the facilitator, and each other,” thus, promoting combined course interaction that fosters continuous collaboration among the students in an online class” (41).

By combining rhetorical understanding and analytical processes we could dispel students’ common misconceptions that physics is too difficult, writing too intense, and online learning too isolated to be successful. This study was based on “Hands-on/Minds-on” learning strategies (Singh 20) for acquiring usable knowledge that is, in turn, internalized and transferred across learning experiences. Ultimately, we combined investigative inquiry in English composition and conceptual understanding in introductory physics in an online environment to promote successful learning outcomes.

### **Physics Instructor**

Learning as a social process has long been established by educational research (Vygotsky, Werstch). While cognitive research has concluded that creative problem solving strategies engage students in active learning, it has also been determined that too much struggle, even in creative activities may inhibit students’ problem solving abilities (Singh 3). Singh also suggests that students sometimes try to disguise cognitive learning tasks, (i.e., knowledge acquisition, retrieval, retention, and transfer) by simply reciting scientific facts, and instructors are often not aware of the difference (2). In many disciplines instructors have begun bridging that gap by using writing assignments to help students explore their learning processes.

Many physics education research studies show that students’ learning improves when they are actively engaged. One way students can be engaged and increase their understating of physics is to talk about what they are doing with peers. As they discuss physics ideas and solve problems together, their comprehension of the material increases. Students’ understanding also increases when they can relate the concepts they are learning to common experiences, building on previous knowledge. Key to this process is acknowledging that, “Competence not only requires factual knowledge, but more importantly requires the development of an organizational structure which allow for efficient retrieval and application of ideas” (Wieman, Perkins, and Adams 396). When my English colleague questioned my satisfaction with students’ abilities to conceptualize physics

based on my current online teaching strategies, we conceived this idea of a formal inquiry-based research project.

Our work together led me to explore the arguments of composition and rhetoric researchers that to successfully fulfill the expectation of any course, students must internalize the discourse of the discipline as a means of articulating the critical thought processes used in problem solving (Beaufort, Carroll). Students can recite facts, but does online teaching promote their scientific literacy? Students often hinge their success on an ability to mimic or bluff their way through a course until they internalize the “language” of the disciplines (Bartholomae). When students completed the course, their physics lexis was often totally forgotten.

The purpose of our research study was to examine students’ abilities to develop scientific literacy by articulating, via writing, these concepts in an online course. Our premise was that by employing recursive writing practices to internalize information, students’ would experience cognitive application and thus, demonstrate conceptual understanding and knowledge transfer of physics principles.

### **Methodology**

Since most of the student discussion in an online class takes place in the form of writing, we decided that the virtual environment was the ideal place to begin our investigation. There would be no major paradigm shift in the way the course was taught. Students could post on a discussion board, contribute to blogs, or write a paper to develop their conceptual understanding. Repeating a definition does not demonstrate understanding; however, explanation of the word via writing is assessable. Most productive was to join a research writing course with a physics energy course, thereby engaging students in contemporary topics, while simultaneously offering them the freedom to develop their individual research agendas. We focused on aligning four major learning outcomes in each course:

English: Analyzing and synthesizing argument, identifying the rhetorical situation and responding effectively, employing persuasion, and incorporating evidence.

Physics: Defining terms, performing calculations, and explaining the concepts of the basic physics laws and principles related to energy; identifying energy processes and estimating their efficiency; comparing advantages/disadvantages of energy sources, including environmental and social impact; and evaluating and creating situational energy plans.

The goal of the course was to give students the background to make informed decisions about their energy use in the future. The course was designed as an entry level natural science elective with a math requirement of high school algebra. Students were evaluated using homework assignments, quizzes, writing assignments, and a final exam. Many students taking this course do not have a strong math background. We saw writing as a way for them to engage with the material beyond a mathematical approach.

Linking these two online courses posed some challenges, because dual enrollments between disciplines rarely happen at the college. Students needed to be simultaneously enrolled in two courses that linked disciplinary content to achieve the Learning Outcomes developed for each. Without the support of an instructional designer, we worked with registration to have each student signed into the courses individually. Students would do more than virtually sit in classes together, they would engage in blended course content.

### **Participants**

The participants in this study were freshmen (18 years or older) taking 100 level courses online. For some of them this was their first online course; others were experienced online learners. The enrollment maximum for online courses at Clermont College is 20 students, and we made the decision early on to require students to be enrolled in both courses (six credit hours) to participate in this study.

### **Measures**

As a way of extending analysis, critical response, and practical application, we created one Blackboard meta-course, which housed the entire curriculum for both courses. Each week of the quarter was assigned a menu button, available to students when they opened the course. Two folders, one for English – another for physics, housed weekly schedules with combined due dates for all assignments, as well as reading schedules and chapter reviews. (Students later offered that they like the advantage of having all of the information in one place.) Several weeks were spent coordinating our readings, assignments, and due dates to ensure writing assignments aligned with the physics topic. For example, Essay 1 was a rhetorical analysis for which students were given the opportunity to analyze the pros and cons of alternative fuel sources for automobiles, chosen from

multiple readings previously discussed in the physics course. Each essay was graded independently for both courses.

By sharing the writing prompts and topics, each of us created a rubric outlining the expectations for each essay. These were shared with the students when the assignment was posted, so they fully understood that each essay was graded by two different instructors with two different sets of expectations intended to reflect the individual learning outcomes of each course. A few areas overlapped (e.g., *successfully demonstrates control of syntax, grammar, punctuation, and spelling appropriate for the purpose and audience*).

The English component of the meta-course included Blackboard discussion board forums and a weekly blog. The forums were used to post a segment entitled *Everyday Language*, which challenged students to make connections between personal and scientific discourse (practical vs. theoretical) while examining words in multiple contexts. Following is an example of a forum students completed in week five of the quarter:

*Multiple meanings: Pressure*

*Scientific language: Force divided by the area over which the force acts*

*Everyday language: To force (someone) toward a particular end; influence*

*Contextual examples:*

*She's under a lot of pressure at work.*

*You need to check the air pressure in your front tires.*

*The pressure caused by a temperature difference in the earth forces steam and molten rock to earth's surface.*

*Think about it: A woman is walking in flat-soled shoes. Her weight is spread over the soles of her shoes. Then she puts on a pair of high heels, and the pressure under her spiked heel has gone up exponentially because the area of each heel has decreased significantly. Similarly, in a volcano, when the temperature in the earth increases, the pressure rises, and the volcano spews molten lava.*

*Is there a connection between everyday language and how the word "pressure" is used in physics? Explain.*

Blogs enhanced the sense of a learning community. Students were asked to post responses to a reading or a specific concept. They were also given the

opportunity to inject interesting articles, websites, or discussions with other peers as a way to highlight their understanding. This low-stakes learning environment was a less formal place where students could “try on” their scientific discourse without feeling exposed or embarrassed.

In the physics component students were evaluated with eight homework assignments, five quizzes, three essays, and a final exam. During a typical week students reviewed a PowerPoint presentation, read the assigned chapter, and completed the homework. Example problems and solutions were posted in Bb for review as necessary. Quizzes were timed and available for a two day period. The three essays required students to research an energy related topic and follow the criteria for the assignment prompt.

For the sake of continuity instructions, prompts, and feedback were all given in similar format to prevent confusion and avoid unnecessary cross-context chaos. The goal was to allow technology to encourage active student participation, not silent contributions. The study also included two anonymous surveys, mid-quarter and end-of-quarter, which provided rich feedback from students, offering insight into how they thought the linked courses were supporting their conceptual understanding. Anonymity offered students an opportunity to confirm or refute our hypothesis that blended assignments reinforced learning in both disciplines.

Weekly planning sessions helped us gauge what needed to be tweaked or changed as the quarter progressed. Though the discussion board forums were posted as part of the English curriculum, we graded those during these meetings and offered students feedback. The rubric specified creative, critical thought about the topic and significant sustained responses to peers. This gave us the opportunity to gauge student-to-student interactions as they explained and assessed (in writing) one another’s work.

The due dates for the essays were the same in both courses, and each instructor autonomously graded them according to the rubric posted for his/her course. After grades were assigned, we discussed the results and compared students’ demonstrated understanding. Using this independent grading method allowed us to give feedback from two diverse perspectives. The outcomes prompted a consensus between instructors that, through writing, students were able to clarify and demonstrate previously static physics concepts, substantiating a commonly accepted principle that, “Writing always helps clarify one’s thoughts” (Feisel). Conversely, negative

outcomes offered us a chance to reflect, re-group, and realign our assignments.

## Results

A review of the final research essays for the courses reveals an increase over previous quarters in the number of times students use scientific terms to describe phenomenon, demonstrating an expanded scientific literacy. When coded for word identification, essays from the meta-course include 18% more usage of identified categories (i.e., types, units, sources of energy) than in essays from the physics course alone. Such a factor indicates students' repeated exposure to the discourse creates a comfort level for engaging in the lexis of the discourse.

In addition, anecdotal data derived from this project validates a link between writing and conceptual understanding in an online STEM discipline. Research by Kirkpatrick and Pittendrigh set the stage for this type of inquiry, as over eight-five percent of the students in that study agreed that their understanding was increased because of the writing they did in the course (163). Having quantitative data could provide additional evidence of our results; however, as some research has concluded, "The question of writing to learn is complex and there are a many variables that limit the ability to reach strong conclusions" (Demaree 239). Void of the student voice, quantitative data alone limits writing to a basic "paint by number" skill set that can be mastered by learning a few simple rules, which tells only a part of the story. It is imperative that the data include students' voices as a way of interpreting the silence of a single cumulative grade.

So, what did the students think? Was this collaboration simply a concocted idea – without basis and meant to appease two instructors who wanted to increase conceptual understanding in two disparate disciplines? Survey responses suggest otherwise:

Q1: Did you find this comparison of common everyday terms and physics terms useful?

A1: Fifty-seven percent agreed that they did.

*"I found it very useful; it really showed me that the definition of an idea is often applicable beyond the intended sense of the word."*

*"I found it useful because it helped tie science topics to everyday life."*



Q2: Would your level of understanding of scientific concepts been higher or lower if the course had not been combined?

A2: Seventy-one percent agreed that it would have been lower.

*“Lower, I feel a lot of my learning from this course came from the research required to complete the assigned essays.”*

*“...lower if the courses were not combined, because not only did physics help me learn them, but English did as well.”*

In terms of grades as the overall objective, one student stated,

*“I’m not the best at English and being able to incorporate science into my English assignments, in my opinion, helped me to receive a better grade.”*

*“The understanding of scientific concepts would have been lower if the courses were not combined, because not only did physics help me learn them, but English did as well.”*

### **English Instructor’s comments**

When students feel insecure they tend to mimic their instructor. Their discourse, much more than simply language (Gee), becomes a false interpretation of what they think we expect, and, as a result, their understanding is almost nil. This happens often in challenging disciplines that are “fact-driven.” As Jewett explains: “Confusion can be caused by the careless use of language in energy discussions. Students consciously or unconsciously imitate a teacher in their use of language and so can confuse themselves and others if they employ or pass on incorrect usage of words and concepts” (149). Writing clarifies our thoughts; it solidifies the mushy, soggy pieces of knowledge we grapple with and congeals them into tangible ideas: “Most teachers agree that writing is one of the best ways to assess what a student truly understands” (Schwaller 123).

In fact-based disciplines that foster indisputable but vague thinking, a letter grade is often a misrepresentation of what students actually know. Factoring in test anxiety, memorization skills, and delayed thought process, how can we predicate, with a single grade, students’ true understanding? This meta-course allowed students more creative opportunities to think deeply – on paper – to analyze, interpret and articulate facts they could

conceptualize and internalize. As other physicists have suggested, “An ability to think about one’s own thinking and monitor one’s current level of understanding is essential for learning” (Henderson and Harper 583). Offering diverse methods of instruction and assessment reveals the legitimacy of a conclusive link between writing and comprehension based on students’ abilities to conceptualize phenomenon.

Evidence of an extended stream of consciousness was present in students’ thought process through ideas they explored via the blog. As students applied these terms we were able to see the links they made between common terms and unfamiliar concepts. One student explained the importance of context in language use: “With most of the words we’ve had to compare, you can tell that there is a connection, but the reader should also be able to notice that they are still looked at as different words, depending on how you use them.”

The essays proved to be a showcase for students’ growing understanding of challenging topics. By analyzing the topics (e.g., speed, force, power, resistance) students were able to conceptualize how these fit into a broader world view of alternative energy for both advocates and opponents. Analyzing students’ written discourse made it obvious to us that students were using their newly developed scientific literacy to incorporate theory and conjecture into their writing. For example, one student’s final research paper went beyond the public debate to suggest reform: “Taxes placed on both gasoline sales and profits...would increase the publicity, funding, and productivity of the development of a useful alternative fuel.” While her argument included a thorough investigation of the viability of alternatives, she also made the leap to include “selling the idea” by intersecting rhetoric and science.

### **Physics Instructor’s comments**

The writing component of the meta-course gave students another medium for understanding physics terms beyond memorizing a textbook definition. The discussion board forums provided a way for students to compare a term’s usage and its relation to familiar language. Their responses and postings in the forums showed me that students do get a better understanding of physics terms when they look at the definition in multiple contexts. The contrast and compare method of learning physics vocabulary was valuable. As one student said, “I really liked being able to compare every word used in physics to how it relates to everyday language and scientific terms.” Another student commented, “I like being able to

read what other students say on this topic...it makes it possible to compare ideas.”

Having students enrolled in both English and physics had diverse results. The essays were better than others from previous quarters, in that they demonstrated a depth of conceptual understanding. For example, when asked about the advantages of coal, one student compared its “relatively high energy density” to the disadvantage of it being “a non-renewable resource.” Such answers require the student to understand the concepts of density and renewable energy – themes often presented as static facts. A rhetorical understanding of how to write a research paper noticeably improved students’ abilities to articulate and explain the concepts. Students were able to critically analyze readings with more insight and awareness of how these concepts are affecting their world.

The difference in overall final grades in the course compared with the two previous quarters was negligible; however, during the design of the online energy course I worked with my colleague to create and incorporate writing assignments similar to what students encounter in a research writing course. We tweaked the rubrics for those assignments to reflect an emphasis on physics pedagogy. As a physics instructor, I knew little about how to teach composition, save what I remembered from my own college days. Three essays make up twenty-two percent of the grade in this course. When we created the meta-course the final essay became an extended research paper where students were challenged to demonstrate analytical, rhetorical, and critical understanding of the topic they chose to research. These essays showcased students’ abilities to conceptualize and communicate what they were learning. Physics education has moved beyond using simple formulaic quizzes and equation ridden exams as an absolute assessment of student learning.

### **Discussion and Challenges**

If the goal is simply to get students to write in a physics course, linking disciplines is unnecessary. It would be less trouble for an English and a physics instructor to meet for coffee, discuss thematic units, and create a writing assignment to align with a specific outcome; however, we sought conceptual understanding that empowers students to gain and apply knowledge. One physics learning outcome required students to define terms and explain the concepts of the basic physics laws and principles related to energy. Students left this meta-course with a sound grasp of this outcome because they were directed to view them through a critical lens

that questioned their validity and examined their contribution to the larger discourse.

This is not to say that the study was without challenges. The initial implementation of cross-disciplinary STEM initiatives requires an academic climate conducive to growth and innovation. Our college was not prepared to execute such a plan, and we became responsible for the pragmatics (i.e., course permission, communication, registration). To be truly effective, cross-disciplinary collaborations like ours must be adaptable across all STEM disciplines with minimal oversight at the instructor level, ensuring they are able to focus on course content and teaching. In hindsight, such a design would become too great of a burden without strong support services. We discovered the limitations that this lack of foresight places on STEM collaborations: “Two major deterrents to progress are the lack of community of science faculty committed to undertaking and applying the necessary pedagogical research, and the absence of a conceptual framework to systematically guide study designs and integrate findings” (Reynolds et al. 17). Optimal success requires a permanent infrastructure that supersedes the prejudices and politics which often accompany cross-disciplinary initiatives.

Just as a writing teacher should not teach physics, a physics teacher should not teach writing. This is not to say that there is not value in the writing assignments given in a physics course; instead, it affirms that writing is more than a basic skill set based on the plaguing question “Where *does* the comma go?” Valid writing instruction emphasizes rhetorical knowledge, audience awareness, and critical thinking, as well as control of syntax, grammar, punctuation, and spelling.

Technology should not interfere with or overpower teaching – but enhance it. We often felt only one step ahead of the students in our quest to use the most appropriate technology to advance the content. Being proficient is not enough; instructors must understand the link between the technology they choose and its ability to affect the desired outcomes (Urban-Woldron).

Similarly, the criteria needed to produce quantitative data should be based on a writing rubric embedded in content knowledge, but such data will continue to be flawed because such learning cannot always be quantified (Demaree). The ongoing debate about grades as an absolute assessment tool remains unresolved. As Henderson and Harper explain, “Unfortunately, the research concludes that the grading (summative) functions of assessment are often overemphasized while the learning

(formative) functions are underemphasized” (583). It has been documented time and time again that some of the greatest minds in our society were often the poorest students. How does such a contrast fit into a substantive research paradigm? We listen to our students. Such an endeavor is not exclusive of facts – data supports anecdotal evidence. It is not a matter of answering a question based on memorizing a formula or explaining a phenomenon in a step-by-step sequence; it is legitimizing what we learn because the observational knowledge we attain can be articulated and transferred beyond the classroom.

### **Conclusion**

Our goal in this research project was to investigate the link between students’ writing and their comprehension of scientific concepts as a means of enhancing learning.

Can students construct scientific knowledge by writing? This research study provides evidence that they can. Writing in this physics course provided students with an additional avenue to interact with the material and conceptualize the principles as valid phenomena. This was evidenced by the critical observations they made in their essays and other writing assignments. Schmidt affirms, “Writing assignments in physics courses help to personalize and reinforce student conceptual understanding by requiring explicit connections and associations to be made with physics principles” (90). The haphazard way we sometimes use words and assume students understand the disciplinary discourse was structured into contexts they could connect to previous knowledge. While we cannot replace formulas with writing, we can conclude that giving students opportunities to provide written representations of how they conceptualize phenomenon will heighten their awareness of the process.

This project was a step toward integrating writing in STEM disciplines, which is crucial to broader advancement of these areas of study for all students. It is our intention that this project provokes others to cross disciplinary lines and extend similar opportunities to other STEM disciplines. Without such provocation we fear the continuation of disciplinary isolation, which limits transference.

Ultimately, the project had a pragmatic bent not anticipated. While they may not understand it, students recognize the contention that often occurs between the sciences and the humanities. They were impressed that instructors from two diverse disciplines were invested in a successful learning experience for their students. When students, without prompting,

surmise that their success is the fundamental goal of the instructors, valuable learning happens. One student said it best: *"The ability to leverage a similar subject for two courses I believe is [a] fantastic idea. I wish there were more ways to do this. The key to this working is having both faculty members on the same page and can work together. I believe that is certainly the case here."*

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