Mapping Writing Concepts Across an Undergraduate Physics Curriculum

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Abstract

Technical communication is essential for a career in physics, but communication skills are often not explicitly taught in physics undergraduate curricula. As a starting point for curricular integration, we investigated where and how writing is currently occurring in the core undergraduate physics courses at University of Illinois Urbana-Champaign. We examined course materials to identify where writing is explicitly or implicitly referenced, the genres that were assigned, and writing concepts that were represented. Analyzing course materials allowed us to identify a wide range of activities and assignments related to writing. We observed that implicit references to writing are prevalent, writing activities are weighted toward upper-level classes, and the most common genres are related to laboratory activities. Writing concepts that occurred frequently in upper-level laboratory courses correspond to disciplinary values of precision and clarity, while concepts of novelty and evidence were infrequent. This type of assessment can help identify gaps in the curriculum, allowing us to be more deliberate about how we develop students' communication skills.

1 Introduction

Writing is an important skill for science, technology, engineering, and mathematics (STEM) professionals, as evidenced by its inclusion in accreditation criteria and reports from the National Academies (e.g. [1, 2, 3]). Communication is an important engineering competency, alongside problem solving and teamwork [4]. Anecdotal reports from employers continue to suggest that STEM curricula need to do more to develop core competency in communication, and engineering graduates report similar needs [5, 6]. Communication skills are one of the four primary skill sets physics majors need to master to ensure career readiness, according to the Joint Task force on Undergraduate Physics Programs [7]. Their 2016 report recommends redesigning or adapting physics courses to provide students with more opportunities to develop communication skills, noting that these opportunities should be infused throughout the curriculum, not confined to one course. Lab courses provide an essential training ground for doing science and scientific writing [8], though writing in physics goes beyond lab reports. Drawing on frameworks from writing studies, we argue that physics students need to develop an awareness of genre and the ability to learn new genres. Indeed, the Joint Task force emphasizes that physics graduates must have "the ability to communicate orally and in writing with audiences that have a wide range of backgrounds and needs" [7].

Our approach to this problem is grounded in a sociocultural perspective on writing, in which writing and the associated tools and practices are highly situated and context-dependent

[9, 10, 11, 12]. A direct consequence of this grounding is that writing instruction cannot be outsourced; it is an enculturation that requires the attention of faculty from the discipline. This perspective also encourages a broad definition of what writing is, including activities as varied as taking notes in lab, reading related work, thinking, looking out the window or taking a run, visualizing data, discussing with colleagues, presenting and answering questions, along with drafting, getting feedback, and revising. Furthermore, echoing the call to infuse writing in physics curricula, Writing Across the Curriculum principles state that writing "cannot be mastered in a single course but is learned over a lifetime" [12]. Writing skills need to be developed along with disciplinary knowledge, and explicit development of writing can also support the learning of disciplinary knowledge [13].

Limited data are available on the distribution of writing in STEM curricula. At University of Illinois Urbana-Champaign, surveys of engineering departments suggest that attention to writing is concentrated towards the end of the undergraduate experience and in a small number of courses (often designated writing/communication-intensive and fulfilling campus-level general education requirements) [14]. Even in STEM courses requiring writing, students are not necessarily given explicit writing instruction [14]. Surveys from the Unites States Military Academy documented graded events requiring written or oral communication throughout the curriculum, increasing in frequency with each year of study [15]. Those authors noted that although these graded events followed a progression across the curriculum from low stakes and individual to high stakes and team-written, the events were not coordinated or scaffolded across the curriculum; they did not report whether or not explicit writing instruction was provided. Co-instruction by STEM and writing specialists is a common model [16, 17, 10] but is usually focused on one or two courses in a curriculum. Reports of vertical integration, or the incorporation of writing instruction across curricula, often highlight two-course sequences, implying a dearth of more comprehensive integration or scaffolding. Notable exceptions related to STEM writing include an eight-course sequence supported by a co-instructor with writing expertise [18] and scaffolding over four years that was developed with foundation support [19].

Working towards the larger goal of infusing writing throughout physics curricula, we sought first to gain a more comprehensive understanding of where and how writing shows up in STEM curricula. Having observed that STEM faculty typically define writing as longer, more formal products, we reasoned that survey approaches were likely to underestimate the presence of writing, particularly for less formal genres such as lab or design notebooks, writing-to-learn activities, and problem sets. We therefore focused our analysis on course materials from the required courses and the writing-intensive courses in one physics department.

2 Methods

2.1 Undergraduate Curriculum and Data Collection

The undergraduate physics curriculum at University of Illinois Urbana-Champaign is designed with a core of required classes and two flexible clusters, Fig. 1, allowing different physics tracks to share the same general curriculum. Students are required to take an advanced composition course, though this need not be in their field. In the year under analysis, enrollment in the physics advanced composition courses was approximately 60% of the number of senior physics majors.

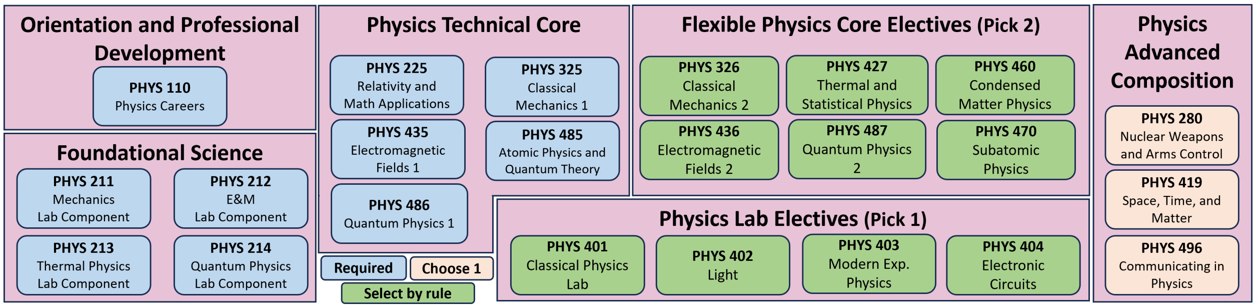

Figure 1: Courses in the core physics curriculum at University of Illinois Urbana-Champaign.

For this work, we collected course materials that were publicly available through course websites. For the majority of courses, the materials consisted of the syllabus and assignment details. We chose to analyze more materials from the lab (401 and 403) and advanced composition classes, because these courses require the most writing, despite the imbalance this introduces when comparing across the full set of courses.

2.2 Analysis

We drew on systematic methods for qualitative coding of the course materials [20, 21]. References to writing or written genres were identified and segmented by topical chain; each topical chain will be, hereafter, referred to as an "instance." The instances were coded using a set of learning goals and shared values related to writing, hereafter referred to as "Learning Goals," which are under by the Writing Across Engineering and Science (WAES) project (https://publish.illinois.edu/waes/) and are informed by conversations with the department being studied here. The Learning Goals framework highlights both skills valued by STEM faculty as well as habits and mindsets that promote better technical writing. Among the skills covered by the Learning Goals are values of precision and clarity, which were prominent in a survey of engineering faculty (for details of the survey methodology see [14, 22]). A simplified version of the goals is provided in Fig. 2. In this paper the coding will be discussed at the level of "Categories," though it was performed at the more granular level of the "Examples."

In addition to employing the Learning Goals as a codebook [2], we attended to themes emerging from our analysis, such as the observation that expectations around writing were most frequently articulated in reference to grading practices, rather than to disciplinary practices. Each segment was also coded as an explicit or implicit reference to writing, based on whether a form of the word "write" was used, or if specific inscription practices across writing modalities were prompted (e.g., creating slides, taking notes, reading a required article). The segments were also labeled according to whether expectations for writing practices were explicitly outlined (e.g., rubric guidelines, rules for emailing instructors). Subsequently, we coded references to writing based on genre for comparison across the curriculum. For instance, we compare how the Learning Goals are implemented in lab reports across courses.

The coding of course materials was carried out independently by researchers from writing studies

Framework for Writing in STEM	
Categories	**Examples**
Mindsets	• Writing is a process; it takes time, planning, and revisions • Writing can help you learn and do engineering and science
Habits	• Reading • Seeking examples • Collaboration • Giving feedback
Precision	• Employ specific language • Attribute sources
Clarity	• Favor simple sentence structures • Adjust presentation for different purposes and audiences
Evidence	• Design experiments and models
Novelty	• Identify and articulate knowledge gaps and novel contributions

Figure 2: A simplified version of the framework of Learning Goals for Writing in STEM. The left column identifies the general categories used in the framework, while the items on the right provide examples in those categories.

and physics, with discussions during initiation to clarify the coding schema and after completing the individual coding to resolve differences. Drawing on grounded theory practices [23], the researchers composed memos documenting observations about conceptions of writing and disambiguations of codes. This collaborative process was used to refine shared understandings of the coding schema and emergent codes. While we did not conduct a full inter-rater reliability analysis, the conversations between researchers from two different disciplines—writing studies and physics—allowed us to better account for the ways in which differences in disciplinary background and knowledge of the physics curriculum might impact curricular assessment. Further, the hybrid approach of inductive and deductive coding [24] allowed us to gain insight both into how physics curriculum materials aligned with the writing values identified in the Learning Goals, and how the curricular materials signaled expectations and values around student writing that were not entirely captured by the Learning Goals.

3 Results and Discussion

3.1 Explicit vs Implicit References to Writing

All of the courses analyzed here included instances referring to writing. As a rough approximation of which courses provide instruction around writing, we examined whether those instances were explicit or implicit (Fig. 3). Percentages were reported to account for the different amounts of materials available for some courses. Looking first at the explicit references to writing, only a few classes are above 50%; these are predominately at the 400-level and either fulfill advanced composition requirements or are laboratory courses. Many more classes implicitly reference writing. An example of such an implicit reference to writing is: ”The notes from each lecture will be posted on the course website.” Making this reference more explicit could be accomplished by adding a recommendation that students review the notes to reinforce concepts from lecture and prepare to reengage with the material. Another instance of implicit reference to writing is: ”We will present some of my slides and many Phys 403 student slides as examples. We can talk about why they are well constructed examples.” Including some motivational context for this reference, such as a comment on how students should draw on these examples for their own presentations, would make the connection to writing practices more explicit.

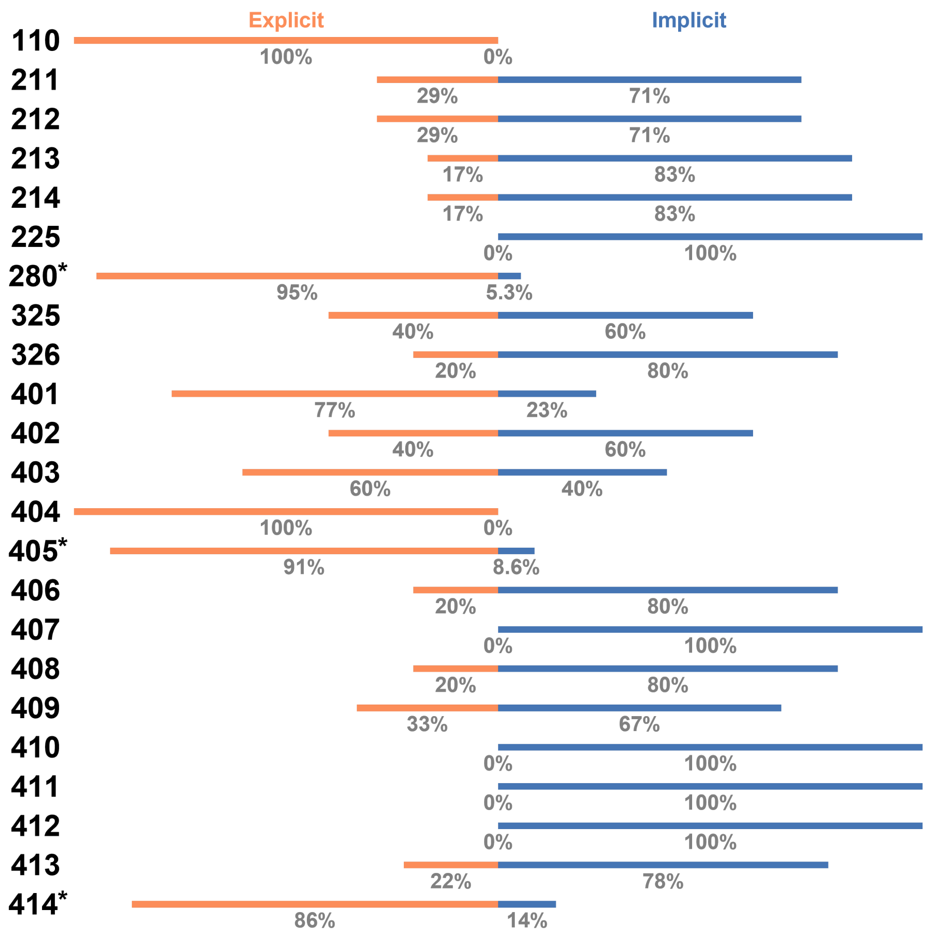

Figure 3: Explicit versus implicit instances referring to writing in each course. Percentages are reported to account for differing amounts of course materials analyzed across courses. Explicit in orange, implicit in blue. *Advanced composition courses

A survey conducted previously in this department identified only the 400-level lab courses and the advanced composition courses as having a significant writing component, and only the advanced composition courses as specifically teaching writing [14, 22]. This result is generally consistent with the analysis of course materials presented here, in that the courses we identified as having the most explicit references to writing aligned with those identified by the survey as having a significant writing component. One discrepancy is an artifact, as writing was added to PHYS 110 after the survey was completed but before the analysis of course materials. However, the references to writing identified here in many other courses indicate that writing is more widespread than the survey suggested, and the fact that many of these instances are implicit may suggest opportunities to more effectively leverage existing course materials and assignments for the development of writing skills.

3.2 Genres Used in Physics Courses

To explore the ways writing is being used in these courses, we also analyzed the genres that appeared (Fig. 4). The advanced composition courses were grouped together, independent of their academic level, because they are specifically intended to develop students' writing skills and therefore might be expected to cover a broader range of genres, which is verified in Fig. 4. At the 400-level, most of the genres are present, due to the laboratory courses. For clarity, some less common genres were clustered together. For example, Interactive Writing included discussion boards, lecture notes, and collaborative questions. Assessment Writing included writing associated with homework and exams.

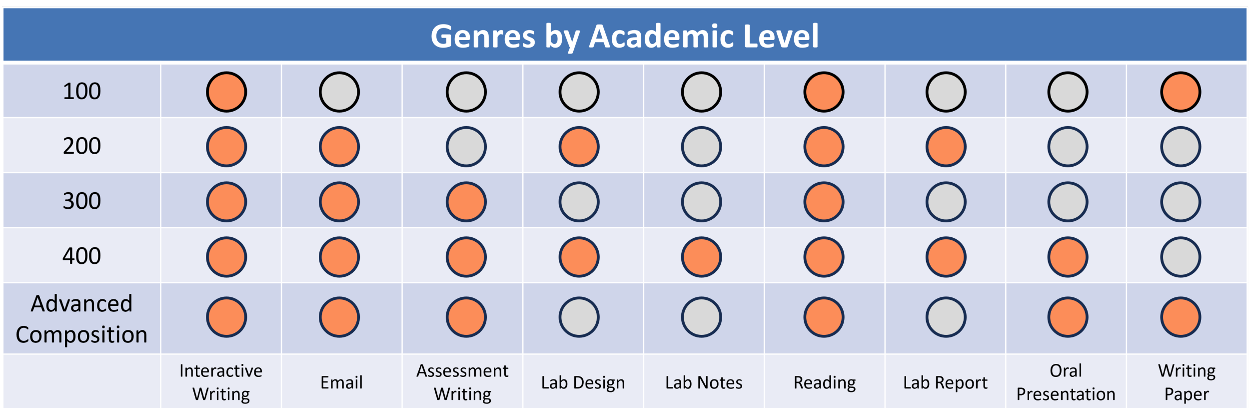

Figure 4: Genres that appear in an academic level are indicated by orange. Advanced composition classes are represented separately.

Figure 4 provides a useful visualization of the types of writing that students are asked to do across the physics curriculum. In this case, the genre analysis shows a heavy emphasis on academic genres such as those related to assessment and papers. Considering the Joint Task force report's emphasis on communicating for the public [7], we note that none of the genre clusters that emerged in our analysis clearly connect to public-oriented genres. However, our analysis did not specifically code for scientific or public audiences; there could be assignments for example under Writing Paper in which a public audience is specified.

Another use for this type of visualization is to get a sense of what a student would experience through their progression in the curriculum. For example, this analysis suggests that students are not assigned oral presentations until their senior year. The 200-level instances of lab design and lab report might provide opportunities for scaffolding across courses, preparing students for the 400-level laboratory courses.

3.3 Concepts Represented in Writing-Intensive Courses

For this analysis, we focused on the most writing-intensive courses, specifically the advanced composition courses (Fig. 1) and two of the laboratory courses (401 and 403). To investigate what concepts were conveyed in these courses, we coded the course materials using a framework of mindsets, habits, and values related to writing (Fig. 2). The advanced composition courses incorporated mindsets, habits, and values from the framework, with the notable exception of Precision (Fig. 5). In contrast, only Precision and Clarity appeared frequently in the 400-level labs, which could either indicate that these concepts are the most important ones for lab, or that the structure of labs does not support the concepts that students require. Taken together, these writing-intensive courses appeared to provide good coverage of the concepts in our framework. One caveat is that physics majors are not required to take their advanced composition course within physics; there could be substantive gaps in this curriculum if an advanced composition course is taken outside of their major department and that course does not cover the same concepts.

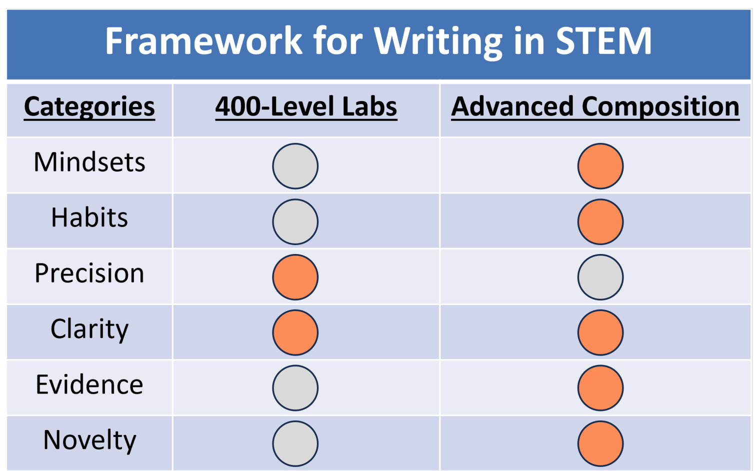

Figure 5: The writing concepts, identified by orange shading, found in 400-level labs and advanced composition courses.

The comparison in Fig. 5 could also be used to reflect back on the framework and its effectiveness in representing the writing skills important to relevant career paths. For example, if one took the Learning Goals used in laboratory courses as representative of the writing skills essential to student careers, it would suggest that the framework includes irrelevant concepts. On the other hand, the coverage of Learning Goals in advanced composition courses shows better alignment with the framework, perhaps reflecting their shared focus on development of writing skills.

4 Conclusions and Implications

- Analysis of course materials for instances referring to writing revealed a broad range of courses involving writing. This approach has the potential to provide a more comprehensive assessment of writing across curricula. While the manual approach used here is labor intensive, some steps could be automated to facilitate more comprehensive and more frequent assessments.

- In this physics core curriculum, explicit references to writing mainly occurred in 400-level laboratory courses and courses designated as meeting an advanced composition requirement. However, the abundance of lower-level courses with implicit references to writing suggest opportunities to increase emphasis on writing by making those references explicit.
- This type of curricular analysis can be used to inform and/or assess pedagogical or curricular interventions. For example, identification of courses using the same genres could suggest an opportunity for scaffolding instruction across courses. The same finding could identify places where the repetition is deemed redundant and substitution of other genres might be appropriate. Alternatively, genres that are underutilized could indicate a gap in coverage of skills students may need.
- The curricular analysis also feeds back into development of learning goals related to writing. For example, although conversations with faculty identified supporting evidence as a core value, this value was not emphasized in the 400-level laboratory courses. This disconnect suggests a discussion topic for the departmental faculty.

5 Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 2013443. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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