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Improving Undergraduate STEM Writing through Common Language as a Tool to Teach Engineering ”Dialects”

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I. Introduction:

The ability to write effectively is an essential skill set of every professional discipline, including Science Technology, Engineering and Math (STEM) disciplines. Its inclusion in the accreditation criteria for applied and natural science, engineering and technology demonstrates this importance. For example, ABET includes the following similarly-worded outcomes in its most recent (2019-2020) version of accreditation criteria:

- An ability to communicate effectively with a range of audiences (applied & natural science general criteria) [1]

- an ability to apply written, oral, and graphical communication in broadly-defined technical and non-technical environments; and an ability to identify and use appropriate technical literature (Engineering Technology Bachelor's degree general criteria) [2]

- an ability to communicate effectively with a range of audiences (engineering general criteria) [3]

Mathematics is not accredited by ABET, but various professional societies associated with the discipline have identified communication as an essential skill. For example, INFORMS (professional society for operations research) gives the following advice in the "Career FAQ's" section of its website:

> "Because a great deal of our work involves the gathering of information, the presentation of results, and assistance in implementing solutions, strong interpersonal and communications skills are vital. In short, *you must write and speak clearly and convincingly* and be able to listen well and deal tactfully with the concerns of others (emphasis added)." [4]

The American Statistical Association similarly identifies the "ability to communicate" in its online curricular guide [5], and the Mathematical Society of America, in its 2015 CUPM Curriculum Guide to Majors in Mathematical Sciences lists students should develop effective thinking and communication skills as the first of its four "cognitive recommendations." [6]

Despite this wide acceptance of the importance of communication skills among the professional societies associated with the various STEM disciplines, works such as those by Boettger and Wulff [7] and Wolfe [8] identify persistent gaps between STEM student writing and the style of writing actually used by STEM practitioners.

To meet standards of accrediting bodies and professional associations, faculty in STEM and undergraduate writing programs have collaborated to address the complex, nuanced, and time-intensive processes of learning to write in one's profession. STEM departments have increasingly drawn on writing centers [9] and courses staffed by personnel with STEM-specific writing expertise to ensure that effective communication is integral to undergraduates developing their professional identities [10].

The value of teaching undergraduates the "five domains of writing knowledge" – genre, discourse community, process, content, and rhetorical [11] – is well established. Research on ways to facilitate students' abilities to transfer that knowledge among core and major courses opens possibilities for developing coherent writing curricula [12]. As students develop understanding of disciplinary genres, such as lab reports and design projects, and address different audiences for those genres, they can refine their ways of thinking and expression of disciplinary knowledge [13]. A coherent curriculum can also support the teambuilding, collaboration, and peer response practices crucial to undergraduates' professional development. Developing a coherent writing program, however, demands extensive time, labor, and resources, and among the most persistent challenges is addressing sentence-level expression.

While undergraduates in their third year can identify points at which their content and rhetorical knowledge "begin to merge" [14], addressing the subtleties of sentence-level expression requires faculty and mentors with disciplinary and rhetorical expertise. Teaching style, syntax, and diction through typical English handbooks cannot effectively address nuances of expression expected by professional readers; however, discipline-specific texts can support writers in learning sentence-level expression [15, 16, 17]. While the demands for learning discipline-specific expectations at the sentence level are considerable, undergraduates can begin to learn "the meaning making aspects of writing" in a new discipline's system of writing [18].

This work's goal is to better identify the "code" or "dialect" that is used in a specific sub-genre of STEM writing: the academic journal. Specifically, written works in the field of mechanical engineering are compared with some from the natural sciences in search of subtle differences in this dialect. This comparison can support faculty in STEM and rhetorical studies in identifying nuances of expression and in articulating those expectations in writing assignments and assessments designed to guide upper-level undergraduates to develop professional-level expression.

II. Methodology:

The twelve-point lexicon introduced in [19] was used again here, and reproduced in this work for convenience as table 1. For STEM journal articles, the "audience" for the written works is defined as an academic one, and the "purpose" of the works is to communicate results. Here the elements of "voice," "development," "style," and "diction," are analyzed on a quantitative basis to provide insight into how these elements manifest themselves in different disciplines' academic writing.

Table 1: Rhetorical language used for analyses

Dimension	Description
Audience	Intended readership
Purpose	Role or intent of work
Thesis	Statement to be supported
Voice	Relationship of author to content
Tone	Author's attitude toward reader and content
Stance	Author relationship to reader
Organization	Method of arranging content
Development	Method of presenting content: explain, analyze; table, figure
Style	Author's technique
Diction	Choice of words
Editing	Process to ensure clarity and correctness of form, expression, and conventions
Conventions	Methods of citing and formatting

Different methodologies were used to analyze the dimensions of style, voice, diction, and development. These are described individually in the sections that follow.

A. Style analysis:

The journals *Nature Physics* and *Journal of Applied Mechanics/Transactions of the ASME* were used as the sources of examples of academic writing in the physical sciences and mechanical engineering communities, respectively. Thirty articles were selected at random from each journal, choosing from those published in 2017 or later. Two paragraphs were chosen from the introduction section of each paper. Introductory paragraphs were chosen for this analysis for two reasons: (1) all the articles so analyzed contained an "introduction" section, providing a readilyavailable “common denominator” for the purposes of a comparative analysis; and (2) the introduction sections were often presented entirely or nearly entirely in prose, making them a source for uninterrupted multi-sentence examples of the authors’ style (as will be shown, later sections of the same papers had significant portions dominated by charts, figures, and equations). The sample was limited to two paragraphs from each article to keep the analysis tractable by manual methods.

Robert Irish’s [16] scale of verbs is reproduced here for convenience. This scale ranks verbs from the “most active” (active verbs) to least active (participles) by degree. For convenience, these levels were numbered 1 through 6 as shown in table 2:

Table 2: Scale of verbs from [16]

1	2	3	4	5	6
Active imperative	Active conditional	Gerunds and Infinitives	Passive verbs, passive conditional	Statement of condition	Participles
The experiment proved the result.	The experiment could prove the result.	The goal is proving (*or to prove*) the result.	The result was proven by the experiment.	The result is negative.	The experiment’s result was a proved hypothesis.

The sentence structure of each paragraph was then annotated by the authors on a sentence-by-sentence basis. Sentences that contained multiple verbs had each verb marked as appropriate. For example:

> Using {*3-gerund form*} Robert Irish’s scale of verbs, the sentence structure of each paragraph was then analyzed {*4-passive verb*} by the authors on a sentence-by-sentence basis.

The process was continued until at least thirty paragraphs from each journal had been analyzed. Then, the number of verb forms of each style were counted to find a total usage and a relative frequency of each type.

B. Voice analysis:

Voice analysis was conducted to identify the presence of the author in the written work. A strong personal presence was considered to be indicated by the use of first-person pronouns; the absence thereof was considered indicative of an impersonal voice. In a manner similar to that used for the style analysis, the number of first-person pronouns was simply counted in the journal excerpts. However, to provide a more meaningful basis of comparison, the presence of first-person pronouns was computed on a pronouns per-sentence basis, and also on an articles-per-journal basis. The latter was performed using the full-text version of entire journal articles (again, 30 from each discipline) as it was noticed that while some article excerpts used personal pronouns, others did not use them at all.

C. Diction analysis:

To examine further the "dialects" or "codes" used by engineers and scientists in the academic journal article, the authors focused on diction, one of the sentence-level dimensions of the common language [19]. The first question focused on choice of verbs used by engineers and scientists when discussing/presenting knowledge and evidence. e.g., "known, "implied," suggested" [20]. The second question focused on verb modifiers noted in engineering and science guides as hedging words, boosting words, and attitude words [20, 21].

Table 3 shows sample words from each of the three categories which were analyzed for frequency of use by engineers and scientists. All 30 articles from each discipline were analyzed using computerized search functions.

Table 3: Word forms used for diction analysis

Diction category	Examples
hedging words	about, almost, essentially, largely, mostly, possibly seemingly, suspected, uncertain, unclear
boosting words	actually, always, certainly, clearly, definitely, never, obviously, undoubtedly, well-known
attitude words	appropriately, disappointing, interestingly, preferably, understandably

D. Development analysis:

Development analysis was conducted by viewing the article as a whole. The relative contributions of prose, graphics (chats and figures) and equations were measured for each journal article. The measure used for the relative contribution of graphics was the “centimeter of column length.” Since both journals used for this analysis are printed in two-column format, PDF versions of the “as printed” articles at 50% scale were used to gauge the relative length of column devoted to prose or to graphics. The overall length of the article from the end of the abstract to the end of the references or appendices (whichever was later) was measured to the closest 0.5 cm. The size of graphics was measured in an identical manner, with graphics spanning two columns counted for their total (two-column) use of space. The relative contribution of graphics to the work as a whole could be roughly approximated in terms of percentage of space devoted to them.

The contribution of equations was measured in an absolute sense by counting the number of indented (i.e. not in the body of a sentence) equations in each work. Whenever possible, the original authors' equation numbering schemes were used, and "sub-equations" (e.g. those indicated by a number and letter) were considered "one equation." An exception was made for the case of some works where in certain sections, the equation numbering scheme was discontinued, but indented equations remained. These were counted manually and added to the numbered equation total.

III. Results:

A. Style analysis results:

Figures 1 and 2 show the relative appearance of the verb forms from [16] using the numerical scale identified in the methodology section. Results are shown for both the natural science journal articles (figure 1) and for the mechanical engineering journals (figure 2).

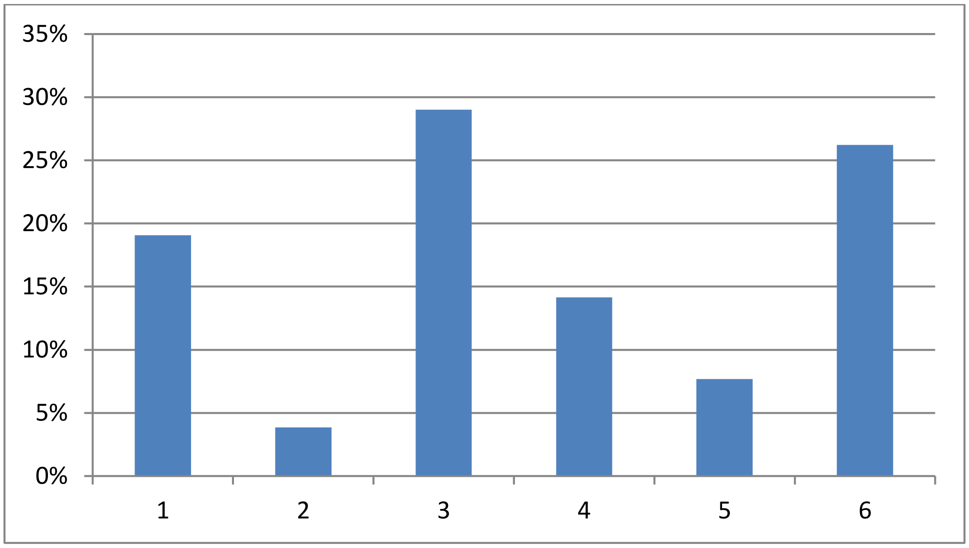

Figure 1: Relative frequency of verb form in physics journals, based on 572 samples.

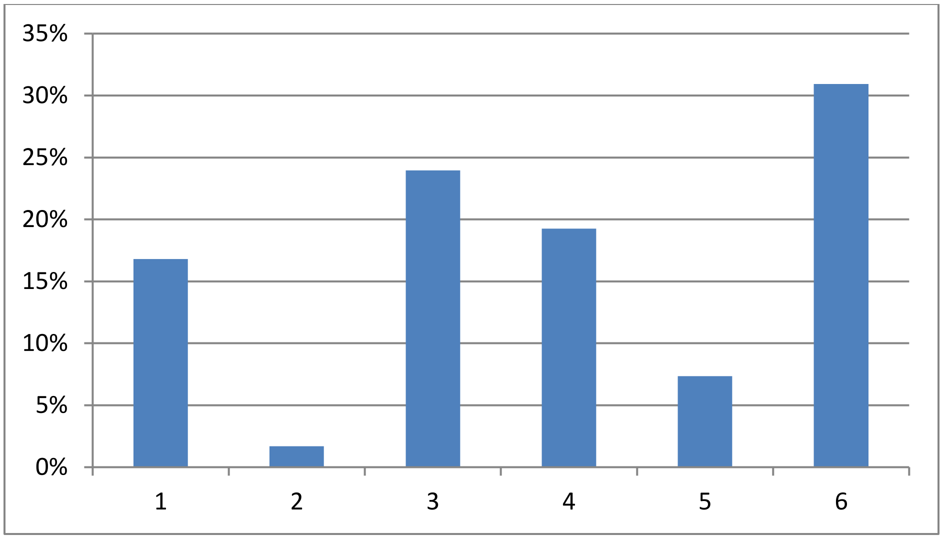

Figure 2: Relative frequency of verb forms in mechanical engineering journals based on 530 verbs.

Overall, the results show a similar pattern, with the largest net difference appearing in verb categories 4 and 6. Here, the engineering journals made a slightly higher use of both the passive form (19% of the verbs vs 14%), and the participle form (31% vs 26%). The physics journals made a slightly higher use of gerunds and infinitives (29% vs 24%). In the remaining verb form categories, the relative proportions of verb category usage were within 2% of each other.

B. Voice Analysis Results:

The results of the voice analysis are shown in table 4, which shows the relative occurrence of personal pronouns in each of the journal article excerpts and also from the analysis of the entire articles.

Table 4: Results of voice analysis

Metric	Physics Journals	Mechanical Engineering Journals
Number of sentences in samples	515	428
Number of personal pronouns		
We	54	11
Our	18	6
Us	1	1
Proportion of sentences with a personal pronoun	14.2%	4.2%
Percent of journal articles with a personal pronoun anywhere	100%	90%

While all the physics articles assessed used at least one pronoun, among mechanical engineering journal articles it was still high (90%), with the caveat that one mechanical engineering journal article that used exactly one “we” in its very last paragraph (to make a personal acknowledgement) was considered to have “no pronouns used” for the purposes of this analysis as no other personal pronouns appeared elsewhere in the entire work. If this exception is not made, then the proportion of mechanical engineering journals with personal pronouns rises to 93%.

C. Diction analysis results:

Summary statistics of the analysis of the articles are presented in table 5.

Table 5: Diction analysis results

Diction category	Frequency in Physics articles		Frequency in Engineering Articles	
	Instances	Percent of articles	Instances	Percent of articles
hedging words	92	80%(24/30)	379	100% (30/30)
boosting words	66	90% (27/30)	129	90% (27/30)
attitude words	12	20% (6/30)	5	6.7% (2/30)

The most pronounced difference in diction is seen in the “hedging words” category, where it can be seen that while a large proportion of articles in both the physics (80% of articles) and engineering (100% of articles) disciplines make use of such diction, the instance of such words was over four times higher in engineering articles. “Boosting words” followed a similar but not as pronounced pattern; here they appeared in an equal proportion of physics and engineering articles (90%), but appeared in the engineering articles at approximately twice the frequency as in their physics counterparts. Attitude words appeared more frequently in the physics papers than in engineering papers (“interestingly” being chief among these) but nevertheless remained relatively rare in both disciplines.

D. Development analysis results:

Summary statistics of the analysis of the articles are presented in table 6.

Table 6: Summary statistics for development measures

Statistic	Physics Papers	Mechanical Engineering Papers
Total length (cm)	179.7	220.5
Length of figures (cm)	58.6	73.3
Average percent figures	32	32.6
Body equations-average count	3.4	21.3

Appendix eqns-average count	4.8	14
Total equations –average count	6.8	22.5

In table 6, “total equations” does not equal the sum of the two rows above it because the “appendix equations” average count was only based on those papers that had appendices. While 55% of physics papers had an appendix of any type, only 10% of the mechanical engineering papers had an appendix. Overall, the average percentage of column space devoted to figures was approximately the same between the two disciplines. However, a marked difference emerges in the number of equations in mechanical engineering papers when compared to their physics counterparts—22.5 vs 6.8 equations. This difference is even more pronounced when appendices are excluded: Here the typical engineering paper had more than five times as many equations as its physics counterpart.

IV. Analysis:

Overall the results show significant overlap between the physics and mechanical engineering disciplines in many areas. Writing style, as judged by verb form, is very similar, with gerunds, passive verbs and participles dominated the verb forms in roughly similar proportions. A personal author presence was found in a high proportion of both mechanical engineering papers (90%) and physics papers (100%). Development and presentation of material favored a roughly 2:1 ratio of prose to figures in both disciplines as well.

However, many differences became apparent as the analysis is expanded beyond these points. The contrast in the number of equations that appear in engineering papers when compared to their Physics counterparts stands out as the greatest difference. While not supported by a suitable summary statistic, it was also noted during the gathering of results that the engineering equations tended to be much longer than their Physics counterparts; the Physics equations that did appear were often notable for their brevity (while neither actually appeared in the samples analyzed, the reader can think of famous examples from Physics such as “$F=ma$,” or “$E=mc^2$”). In contrast, in general, the engineering equations were much more involved, and often incorporated extensive matrix representations of systems of simultaneous equations that nevertheless were considered “one equation” for the purpose of numbering. Also, because many of the engineering papers employed numbering systems that also used letters (E.g. Eqn 10a, Eqn 10b, etc.), the engineering equation count likely underestimated the true average number of equations in any given work.

Physics papers also employed personal pronouns at a rate more than three times higher than their engineering counterparts. The exact reason behind this difference is unclear: it may be artifact of the content of engineering papers, with their greater emphasis on application, a result of a subtle author bias against their use, or even editorial discretion. Exploration of this reason is suggested as an extension.

As noted in the results section, there were significant differences in diction between the two disciplines. Interestingly, despite a higher rate of equation use in the engineering articles (five times the rate as in the Physics papers), there was also a four time greater use of "hedging" words in the same works. While these results may appear to be contradictory—e.g. greater equation use is typically associated with a more exacting, quantitative approach—it is possible that the greater use of the hedging words in the engineering works is actually an attempt by the authors to offset or balance undue emphasis on the illusion of precision that such extensive use of equations convey. Exploration of this phenomenon is suggested as an additional extension.

Although not an objective of this investigation, while gathering data it was noted that the use of appendices in Physics papers was considerably higher than in their engineering counterparts. Only 10% of the engineering papers had any appendices at all. In contrast, 70% of Physics papers had appendices, many containing extensive information on methodology, mathematical development, and manipulation of equations. In some cases, the Physics paper appendices had their own separate lists of references.

V. Conclusion

STEM faculty can support their undergraduate majors in learning to write effectively by sharing a common language for assigning and assessing writing and by teaching a system that guides writers' rhetorical choices in the genres through which they express professional knowledge. When systematically embedded in course work, the twelve-point lexicon can support writers in embracing rhetorical knowledge as an integral part of their emerging professional identities. As they develop understanding of how the larger framing concepts of audience, purpose, and voice guide structural choices about organization and development, writers can, over time, make the more nuanced sentence-level choices about style and diction.

Sentence-level analysis of academic journal articles as a specific sub-genre of STEM writing in different fields opens possibilities for faculty to identify, teach, and assess their professional "codes" and "dialects." Collaborations among STEM and writing faculty can create institution-specific venues through a campus-wide or department writing center, courses supported by faculty or staff with discipline-specific writing knowledge, independent writing programs, or similar writing-in-the-disciplines venues.

Future research can analyze the remaining dimensions in the lexicon in the academic journal articles in the fields addressed herein as well as "codes" and "dialects" in the many genres of STEM. Strategies for how faculty in STEM and rhetorical studies develop collaborations, materials, theories for practice, and subject-matter expertise outside of their discipline are also an area for further study, as are student strategies for understanding student development of writing expertise.

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