A Math-Based System to Improve Engineering Writing Outcomes

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Introduction

This paper documents an ongoing engineering education project that partners the development of a new method for teaching engineering writing through the lens of mathematics, with the advancement of a university assessment initiative. Since spring of 2013, the project has been staging system trials in both a writing class for engineers and an engineering machine design class. In the latter case, the strategy is to thread compact Just in Time (J.I.T.) instructional modules into technical units of study that require status report memos or a final report. This aspect of the project is a partnership between the author—an engineering communication specialist and experienced mechanical engineer who now teaches for a university writing program—and a senior mechanical engineering professor and department co-vice-chair—seeking to resolve specific problems in teaching engineering communication. An internal grant awarded by the university's office of the provost supports the project's activities in the stand-alone engineering writing class as well as in the engineering design class.

For several years, the author himself has been pioneering an alternative approach for teaching professional writing skills to undergraduate engineers. The system is built around two premises: that engineering majors share literacy in the language of mathematics; and that these learners respond well to traditional, stair-step pedagogy which builds upon core skills to achieve increasing levels of competency. The method employs three levels: *Level One* uses arithmetical and algebraic principles to understand sentences as equations with the parts of speech as variables. *Level Two* focuses on more complex applications of "sentence algebra" to help engineering writers troubleshoot common sentence-level errors and develop a clear, discipline-specific style. *Level Three* uses flowcharts as algorithms to teach the rhetoric behind effective document structures. The system's quantitative approach and bottom-up paradigm make it user-friendly for engineering students by guiding their ascent toward writing mastery using an approach already encountered in the students' studies of math, physics, chemistry, and other STEM disciplines. The author is encapsulating this new math-based approach for teaching engineering writing in a modularized textbook manuscript.

Paired with the project's purpose of teaching writing within a math landscape is its effort to strategically evaluate project impact through assessment. While it is top-level linked to ABET's general student outcomes criterion (g) "an ability to communicate effectively," the project's course- and assignment-level objectives align with more narrowly scoped, concrete outcomes. For example, project assessment measures an engineering student's ability, given a specific writing task, such as generating a status report memo, to design a document using an effective structure and to align that document's message with purpose, audience, and context. To measure assessment outcomes, the project uses Kirkpatrick Scale 1, 2, and 3 instruments—including scaled, pre- and post-activity perceptual evaluations, "minute papers," and analyses of sample papers from the engineering design class.

Background and Context

Over the years, there are two main ways in which writing education has been integrated into engineering curricula—the traditional Letters and Sciences approach, in which an English professor instructs many students, some of which happen to be engineering students; or in newer and more concentrated cases, the engineering students participate in writing and communication classes designed specifically for technical writing in engineering industry.

While the traditional systems of departmental teaching remain prevalent in writing instruction, some conclude that this style of teaching is counterproductive for engineers[1]. This cohort advocates that a curriculum centering around technical writing and succinct descriptions of processes, rather than analysis of themes in fiction novels, is a better, and more effective, use of an engineering student's time and energy. One such program is the semester-long Undergraduate Advanced Writing Communication for Engineers course offered at the University of Southern California, in which students gain writing and public speaking skills by writing for the school's engineering magazine[2]. The audience of the magazine is diverse, and therefore challenges students to communicate technical ideas in such a way that people without knowledge of industry-specific jargon can still understand. Additionally, a semester-long graduate course at the University of South Carolina is designed to prepare graduate students to write an engineering manuscript with the specific intent of being peer-reviewed and published[3]. The content of the course includes specific instructions on the purpose of and information in the four sections of a typical engineering research article.

At K.U. Leuven in Belgium, a technical writing course has been implemented that centers around a checklist of goal writing abilities[4]. Here, each of the writing courses taken by engineering students is taught by a professor with an engineering degree him/herself. The University of Canterbury, in New Zealand, has piloted a program that has forsaken individual communication courses and instead has students improve their work using feedback from their writing in professional courses[5]. In fact, a professor from Michigan State University asserts that engineering professors potentially provide the best example of technical English, as they consistently review and write journal articles and dissertations[6]. At Louisiana State University, an initiative is in place that features Communication-Intensive technical courses and labs[7].

As for a mathematical approach to engineering writing, the literature reveals little. Current programs incorporating this sort of paradigm appear to be missing or in their infant stages. While the system at K.U. Leuven extensively uses standards, checklists, and tables[4] to steer students through their curriculum, there appears to be no usage of math metaphors and symbols, as featured in the new system referred to in this paper. There are, however, quite a few programs that integrate math and writing together so as to reinforce math principles and foster critical thinking in students[8]. This approach improves engineering students' discipline-specific writing skills through the quantitative, concrete, objective lens of engineering. Most would agree that, within the pedagogy of teaching engineering writing, opportunities for improvement do persist, and that writing through the lens of math—the system explored in this paper—is an intriguing instructional concept for math-language experts, such as engineers. As described by Natalie D. Segal, mathematics and English can and should work to form two grammars[9], both of which connect and interact to allow the most effective and comprehensive communication of ideas. The spirit of this type of forward, and grantedly maverick, thinking buttresses the premises of sentence algebra and document algorithms.

Brief Overview of the Sentence Algebra and Document Algorithm System

Level One

Robust, well-built documents are made out of robust, well-designed sentences. Thus, whether learned through the lens of contemporary linguistics or the lens of math, the system posits that it makes good sense for engineering writers to possess a functional understanding of sentences—what goes on, and why, between a sentence's initial capital letter and terminal punctuation mark.

To gain insight via math metaphors and symbols, the system defines the eight functional roles words can play in a sentence and then assigns each role a variable:

N = a noun	M_v = an adverb
V = a verb	L = a preposition
X = a pronoun	C = a conjunction
M_n = an adjective	I = an interjection

Next, the system establishes that words, by themselves, are static data—images, descriptions, dictionary definitions. However, when a noun (N) and verb (V) combine together, the sum produces a phenomenon called *spark* (N + V → spark). *Spark* is the synergy that occurs in sentences that allows individual words to go beyond their static meanings and collectively create dynamic units of human thought. At the center of a basic sentence, there is a spark-producing N + V pair.

In the system, *flow* is a corollary to the principle of spark; sometimes a part of a sentence's spark-driven dynamic charge *flows* beyond central N + V pair to a second object. From here, the system establishes that, in sentence formulas, addition (+) governs nouns, verbs, spark, and flow—as well as prepositions, conjunctions, and pronouns—and multiplication (*) governs words, and groups of words, that amplify specificity—adjectives (noun modifiers) and adverbs (verb modifiers). The system develops formulas for five basic sentences:

$\mathbf{B_1 = ((N_s \text{ or } X_s) * M_n) + (V_i * M_v)}$

- the center of a B_1 sentences is a subject noun and a stand-alone verb (intransitive)

$\mathbf{B_2 = ((N_s \text{ or } X_s) * M_n) + (V_t * M_v) + ((N_o \text{ or } X_o) * M_n)}$

- the center of a B_2 sentence is a subject noun and verb (transitive) pair that transmits "flow" onto a second noun (object)

$\mathbf{B_3 = ((N_s \text{ or } X_s) * M_n) + (V_t * M_v) + ((N_{oi} \text{ or } X_{oi}) * M_n) + ((N_{od} \text{ or } X_{od}) * M_n)}$

- the center of a B_3 sentence is a subject noun and a verb (transitive) pair that transmits flow onto a second and third noun (direct and indirect object)

$\mathbf{B_4 = ((N_s \text{ or } X_s) * M_n) + (V_t * M_v) + ((N_{od} \text{ or } X_{od}) * M_n) + ((N_c \text{ or } X_c) * M_n) \text{ or } (M_c * M_v))}$

- the center of a B_4 sentence is a subject noun and a verb (transitive) pair that transmits flow onto a second and third noun (direct object and object complement) or a second noun and adjective complement (direct object and adjective complement)

$$\mathbf{B_5 = ((N_s \text{ or } X_s) * M_n) + (V_l * M_v) + (((N_p \text{ or } X_p) * M_n) \text{ or } (M_p * M_v))}$$

- the center of a B_5 sentence is subject noun and a verb that links the subject noun either to a second noun (predicate noun) or a noun modifier (predicate adjective).

Figure 1 (see below) shows a basic text sentence parsed into functional units, first, using sentence algebra and, second, using sentence diagramming. Note that in the sentence algebra parsing, the article "the" is elliptical, or assumed.

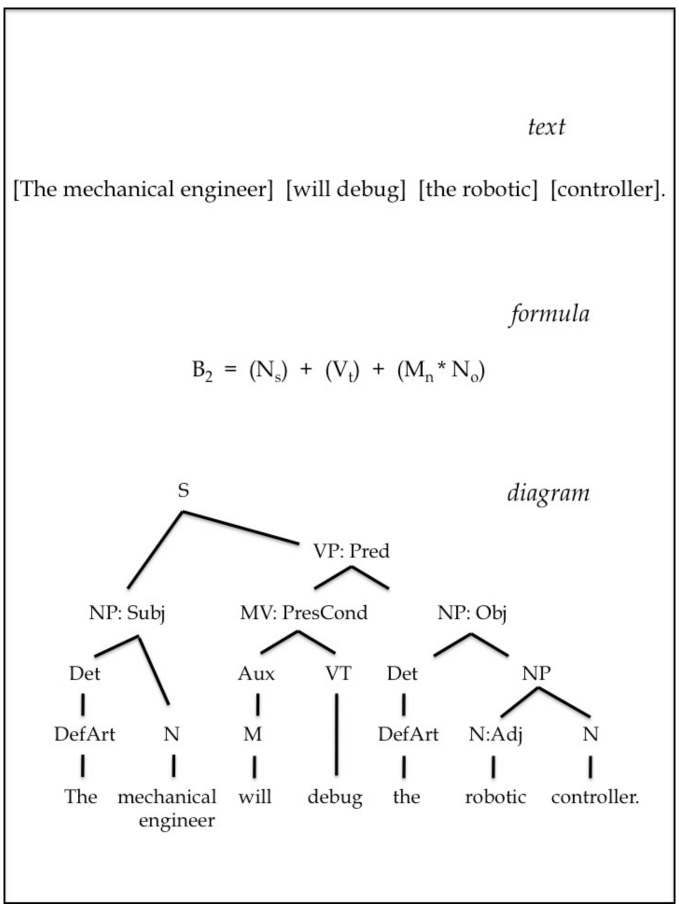

Figure 1--A Sentence as Formula vs. Diagram

Once the engineering student learns how language code translates into math code, the student can further develop his or her sentence-level skill set, learning how to combine, invert, manipulate basic sentence units into advanced sentences.

The following is an illustration of sentence algebra being taught using engineering content/context:

> Consider the sentence-algebra equation for a basic sentence (B_2) …
>
> $B_2 = (N_s * M_n) + (V_t) + (N_o * M_n)$
>
> where: N_s = subject noun word(s)
> V_t = transfer action verb word(s)
> N_o = object noun word(s)
> M_n = noun modifier word(s)
>
> Now, as complement to code, consider the following strand of technical text …
>
> "The new | micro-robotic arm | has | six degrees | of freedom."
>
> Here, moving left to right, the language equivalent to M_n is "The new" and the equivalent to N_s is "micro-robotic arm." Recalling the Basic Math Laws (Commutative), and remembering that sentence-algebra equations feature top-level logic and, consequently, do not code articles, dissect compound nouns, nor parse prepositional phrases functioning as modifiers—can you figure out the rest?

Level Two

Level Two applies sentence algebra toward optimizing, tuning, & troubleshooting sentences and sentence streams known as paragraphs. Some of the techniques taught in Level Two are as follows:

Eliminate Imposter Sentences by Doing a First-pass Scan

- scan for faulty sentence equations, basic and advanced

Do Grammatical Bookkeeping and Reconcile Disagreements

- subject-verb agreement error ($N\# = V\#$?)
- pronoun reference errors ($N_{antecedent} \leftarrow X$?)
- modifier location errors ($M_n \rightarrow \ldots \leftarrow N$?)

Signal Process Points within Sentences Using Commas, Dashes, and Other Devices

- set off introductory elements
- set off nested elements—parenthetic expressions and restrictive clauses
- indicate tacked-on restatements, amplifications, expansions, and lists

Symmetry to Sentence Designs

- design lists using parallel structure, etc.

Strive for Specificity and Concision

- be exact, precise, and accurate in the phrasing of all sentence elements
- a good litmus test for specificity are the prompts: who, what, when, where, why, and how (5W+H)

Level Three

Though templates and formatting vary from company to company, a universal set of go-to structures underlie both long and short documents. The author's system presents these structures as *document algorithms*, which guide the logic and flow of text on the page, just as program algorithms guide the syntax, lines, and subroutines of computer code. Each algorithm is designed around a Mode. Figure 2 (see below) shows a front-end proposal's algorithm constructed using the Mode of Persuasion. This algorithm guides a document to advance a "win-win-win" argument that satisfies engineer/writer, management/client, and stakeholder/end user—in order to procure project funding and authorization.

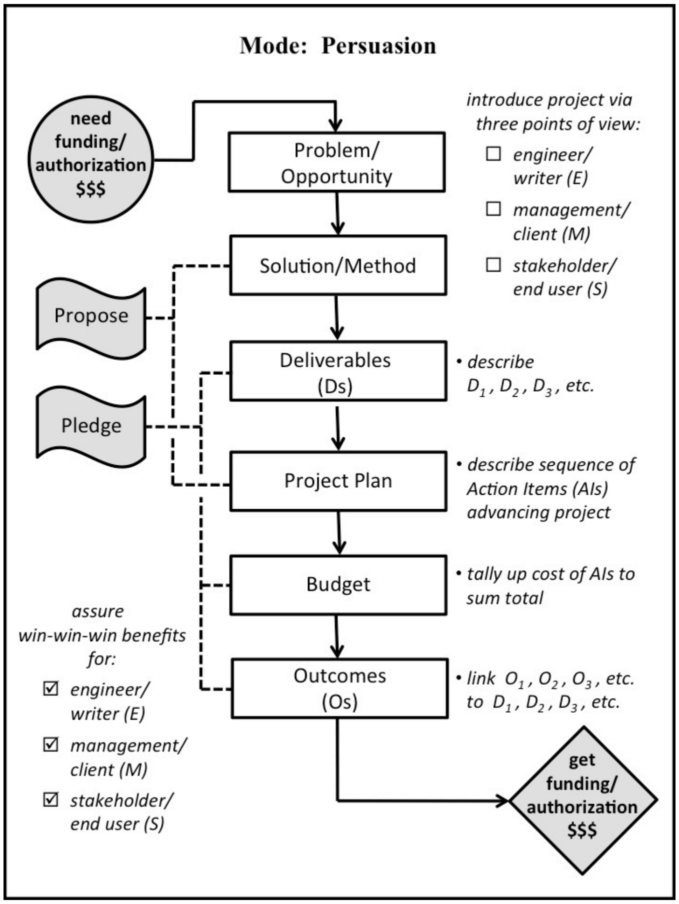

Figure 2—Algorithm for a Win-Win-Win Proposal

Other document algorithms include those for a project report (Mode of Evaluation), a bottom-line-first status report memo (Mode of Inversion), and a technical brief to a nontechnical audience (Mode of Translation). Figure 3 (see below) depicts the algorithm for a project report involving decision-making, in particular, a data-driven argument for a winning solution.

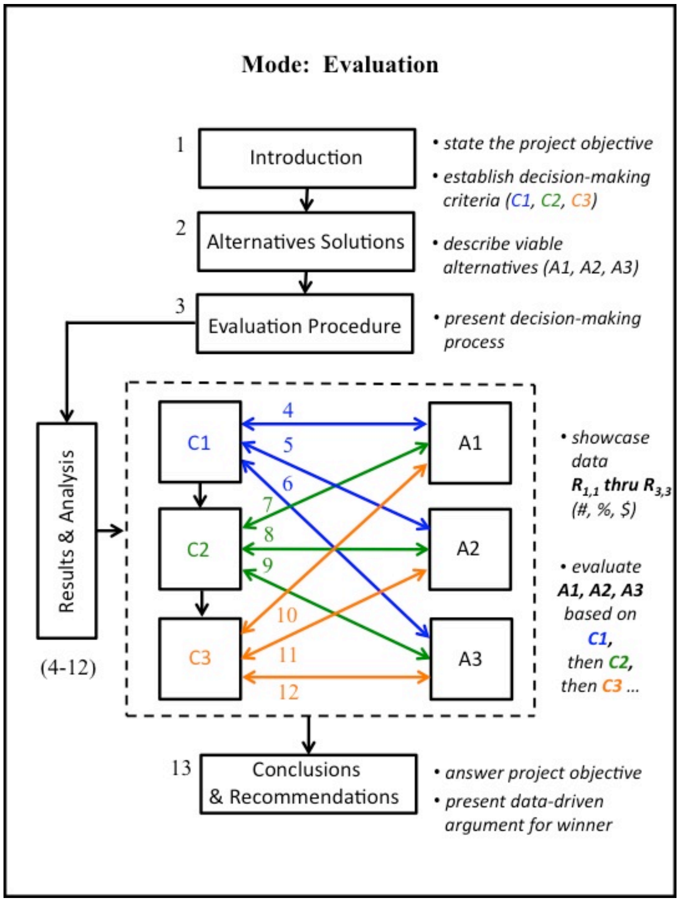

Figure 3—Algorithm for a Winning Solution Among Three Alternatives

Methodology of System Trials

<u>*First Trial*</u>

Engineering Writing Class: The first round of assessment and test teaching took place Spring Quarter 2013, academic year 2012-2013, with initial focus placed on the *sentence algebra* part of the system, although the students were also exposed to several *document algorithms* for informal observation. The experimental subjects were 19 upper-division engineering students enrolled in the author's engineering writing class. For this cohort, the over-arching program-level objective was ABET general student outcome criterion (g) "an ability to communicate effectively."

The class' specific Student Learning Outcomes (SLOs) were as follows:

1. possesses a general understanding of how engineering communication integrates into engineering practices and why it is an essential core skill for engineering professionals.
2. given a specific engineering writing task, can assess associated purpose, context, and audience (wants, needs, and level of technicality) and then align and aim document message accordingly.
3. can write in an effective, discipline-specific style that conveys content *concisely*, *clearly*, and *correctly*.
4. can identify and use common, discipline-specific document structures (e.g., project report, project proposal, and status report memo) in engineering writing tasks.
5. can deliver effective oral presentations that incorporate public speaking best practices, Power Point slides, and multimedia technology.

For the first trial in the writing class, instruction targeted SLO #3, and consisted of a series of three, 1-hr, in-class lecture/workshops, three online-delivered sets of practice exercises, and assigned reading from the instructor/author's textbook manuscript. To ensure class consistency and quality, in preparing the class syllabus, the instructor set a goal to deliver approximately 75% existing, validated course materials balanced with 25% new, experimental course materials.

The assessment process selected for the first trial activity was a Kirkpatrick Scale 2 pre- and post- test measuring "delta-learning." Here, specifically, the learning was tied to sentence-level *correctness*, with the key metric being Andrea Lunsford's well-known, published, and juried list of *Twenty Common Errors* (see Table 1 and corresponding source link in Results, next section). The instructor decided not to test for *concision* and *clarity* during the first trial, in order to avoid confounding factors, but did so with the intention to add concision and clarity criteria in a subsequent trail.

At the beginning of the class, for a diagnostic writing sample during the first meeting, the instructor assigned the students to respond to the following prompt:

> PROMPT: Given 45 minutes of dedicated writing time, discuss (in several paragraphs or so) your lower-division (freshman/sophomore) college experience, focusing on how your lower-division coursework contributed toward your development as a successful, B.S.-degree engineer. You might want to cover some of the following points. What about the university's academic program

> met your expectations? What surprised you and/or happened in your lower-division experience that you did not expect? What were some high points? What, if any, were some low points? Please structure your response to have a beginning, middle, and end. However, the beginning and ending can be concise, as short as one sentence. This is not a formal "essay." When you have completed this activity, upload the file to your online DropBox. Thanks for your input.

Subsequently, the writing class' T.A. evaluated all of the student responses for presence of Lunsford's Common Errors. The T.A. was also required to do the activity. The instructor took the T.A.'s response and loaded it with one occurrence each of all 20 of the Lunsford errors. Next, during the second class session, the instructor briefly discussed the 20 common errors, and then distributed copies of the loaded short document to the students, asking each student to read through the document and underline each occurrence of a grammar, mechanics, and/or spelling error that the student came across. Thus, the loaded document served as pre-test vehicle. In this activity, the students were not required to label errors with a name or number, just to underline errors with a pen or pencil.

Afterwards, the T.A. evaluated the diagnostic writing samples and pre-tests, and then inventoried errors. To close the loop, at the end of the academic quarter, after the students had received a complete series of instructional modules on sentence algebra, the instructor had the students evaluate and inventory a second loaded document. Post-test instructions were identical to the pre-test instructions. The instructor did not inform the students that they were evaluating the same loaded document a second time. Table 1 in Results shows anonymous class-level results for the diagnostic, as well as for the pre- and post- tests.

Engineering Design Class: During the first round of assessment and test teaching, Spring Quarter 2013, academic year 2012-2013, the writing instructor began a partnership with a senior mechanical engineering faculty and department co-vice-chair. The agenda of this partnership was to investigate new methods and best practices for assessing and improving student writing in engineering classes—particularly report intensive classes in the engineering curriculum's design series leading up to senior capstone projects.

Both the writing instructor and engineering professor begin their collaboration with a shared interest in gaining further insight on how to improve instruction in the writing program class for engineers, so the class articulated optimally and relevantly into applied writing activities within the mechanical engineering major. Unfortunately, Engineering Writing is an impacted writing-program class, and, consequently, a large number of engineering students enter the mechanical engineering design series with general writing instruction rather than discipline-specific writing instruction.

The writing instructor and the engineering professor both recognized that one solution to the shortfall would, of course, be adding more sections of Engineering Writing to accommodate more engineering students needing to fulfill their upper-division writing requirement with a "best fit" class. However, at the beginning of their partnership, the writing instructor and engineering professor also recognized that another writing education solution for engineering students—possibly equivalent to a stand-alone engineering writing class—would be to integrate Just in Time (J.I.T.) instructional modules into engineering design classes. This delivery method would enable engineering students to learn more about discipline-specific writing practices and forms when discipline-specific need for these skills peaked.

At the onset, the challenge presented by the J.I.T. strategy was twofold: first, could on-target J.I.T. modules be designed to be compact enough so that they could thread into a design class' already stretched syllabus without taking away from that class' technical content? And, second, since the design classes were double or more the headcount of smaller-size writing program classes (25 students maximum vs. 50+) would the insertion of writing instruction, above and beyond the standard amount of routine, non-coached report writing, present an unwelcomed amount of additional time spent on paper grading for the engineering professor and, more so, the professor's T.A.?

To assess opportunities for efficient, effective, and non-interruptive instructional interventions, the writing instructor began the collaboration activity with the engineering professor by regularly attending the professor's upper-division machine design class for the entirety of Spring Quarter 2013. In forging this arrangement, the instructor and professor furthermore agreed that they would explore and try two small-scale interventions "informally" during the initial observation. Then, after summer holiday, they agreed that they would leverage what they learned Spring 2013 and try a more structured approach Fall 2013.

As the writing instructor monitored the engineering professor and students undertaking the 10-week machine design class, the writing instructor observed the professor tasking the students to write a sequence of four short status report memos during the beginning and middle of the quarter; and then assigning students to write a long-form design report for the class' major project. The project called upon the students, in teams of four, to design a bicycle rack for a motorcycle, with rigorous static and dynamic stress analyses informing material choices and sizing.

After reviewing the first round of project status report memos, the writing instructor developed and delivered two handouts, one on engineering writing, in general, and another on writing memos specifically. The writing instructor also presented two 15-minute talks to the design class students on usage of the handouts. See appendix for examples of the two handouts. Informally, the writing instructor and engineering professor observed that better memo quality did appear to result from the writing instructor's handouts and brief talks, which consumed 30 minutes total class run-time.

In addition, the instructor and professor observed that the students' writing as well as the T.A.'s ability to grade the writing appeared to be assisted by the collaborative effort between writing instructor and engineering professor to improve the writing assignment portion of the professor's engineering design project guidelines and handouts. In conjunction with their work adding clarity to the writing portion of the class' design assignment, the engineering professor and writing instructor, as well as the T.A., agreed that the class' paper grading rubric also invited improvement. This refinement effort resulted in the development of five major grading criteria:

> **Completeness:** The extent to which a student design team's memo fulfills the assigned tasks and specifications for the current design phase. Given that weekly tasks build upon prior assigned work (earlier memos), and can require modifications to prior completed work, a *complete* memo describes and discusses modifications to earlier work, as well as presents new findings.
>
> **Quality:** The extent to which the student design team's memo presents design deliverables that are viable, elegant, and robust. Submitted work should be technically correct, yet also reflect a degree of down-selection and optimization that results from quantitative design tradeoffs (e.g., square versus round sections, hollow versus solid, best material selection, weight minimization).
>
> **Velocity:** A measure of the memo's communication efficiency and effectiveness at the paragraph-level. An efficient and effective writing style allows the reader to decode a document's message smoothly and at a speed in sync with the reader's ability to uptake information. On the contrary, poorly written streams of English language code (i.e., chains of sentences) unpack sluggishly for the reader and often require him/her to "double back" and reread. During this stall in forward momentum, the reader struggles to "figure out" ambiguities, infer missing pieces, and reconcile flaws in logic. Examples of elements that can slow velocity of a stream of text would be logical fallacies, contradictions, and cryptic expression of ideas (i.e., failure to provide the reader with an essential/necessary piece of information because the writer feels this information is "obvious").
>
> **Noise Level:** This criterion, first created by David Beer[10], is closely related to velocity but applies more to writing at the sentence-level. "Noise" interferes with the reader's fundamental ability to

decode textual strands that link together to form paragraphs. Instead of getting in the way of overall message flow, noise is a measure of sentence impurity. Excellent sentences are concise, clear, and correct. They channel clean signals. They are not full of static, glitches, and unwanted rogue waveforms. Some examples of "noise" would be dead wood (extraneous verbiage), jargon (buzz words and gratuitous frills), unnecessary passive phrasing, out of parallel phrasing, and inexact/incorrect/awkward phrasing (grammar, mechanics, punctuation, and spelling errors).

Packaging: This criterion judges a document's aesthetic, mostly in the area of layout and typography. Some examples of poor packaging would be single-spaced chunks of text longer than 8 lines, sloppy formatting, and font-size too small. In the real-word, there are well-established conventions that define what looks "professional." Just as there is a pre-defined way a CAD-produced layout should look on the page, a standard set of conventions also guide what an engineering document should look like on the page. Like it or not, how a document "looks" is important.

A couple of times during the quarter, the engineering professor queried the design class students using the vehicle of "minute essays," i.e., micro-short, on-demand writing assignments asking students to check-in regarding the class' on-going experiment in writing instruction improvement with responses to the prompt blast—"What do you like...? What do you like...? What don't you like...? The responses were written on 3x5 cards. During the first trial, the minute essay results could be summed up as "generally positive," though nothing more beyond this distilled that would be worthwhile inserting into Results. Beyond the minute essays, during Spring 2013, the partnership between the writing instructor and engineering professor did not produce and administer any additional assessment instruments. The partnership did, however, posture the project for focused continuation and deeper intervention the next time-around. In addition, since the students submitted their status report memos online, a complete set of samples of memos 1, 2, 3, & 4 were retained. As is subsequently explained, in the second trial procedures, as well as revealed in Table 4, Results, the Spring 2013 student sample papers were revisited and further evaluated, Fall 2013.

Second Trial

Engineering Writing Class: The second round of assessment and test teaching took place Fall Quarter 2013, academic year 2013-2014, with expanded focus placed on the *document algorithms* part of the system. Like before, the experimental subjects were upper-division engineering students enrolled in the author's engineering writing class. This time class size was 21 rather than 19. As usual, the over-arching program-level objective was ABET general student outcome criterion (g) "an ability to communicate effectively." Fall Quarter 2013, instruction targeted all five class-level SLOs cited above, with particular test-teaching emphasis placed on discipline-specific structures, SLO #4.

On behalf of sustaining the goal of 75% old and 25% new materials, the instructor reduced the amount of time spent on test teaching sentence algebra materials, and instead placed more emphasis this round upon test teaching trial *document algorithm* materials. Specifically, the instructor developed and taught three new, experimental modules, centered around the documents algorithms for a project proposal (see Figure 2, previous section), a project report recommending a best choice among three viable alternatives (see Figure 3, previous section), and also a interim status report related to an on-going project (See Figure 4 below). Another new resource for objectifying the study of engineering documents, which complemented Lunsford's List of Twenty Common Errors, was a new handout listing Twenty Essential Features of an Engineering Document. The Appendix contains a sample copy of this handout. Delivery of the three new modules involved three 1-hr, in-class lecture/workshops, three out-of-class writing assignments, handouts, and assigned reading from the instructor/author's textbook manuscript. In this paper, the three preceding modules are considered J.I.T.s. An abridged version of one of these—the module on interim status reports—became a suitable J.I.T. module to thread into the machine design class, at 30 minutes run-time, as opposed to 1 hr.

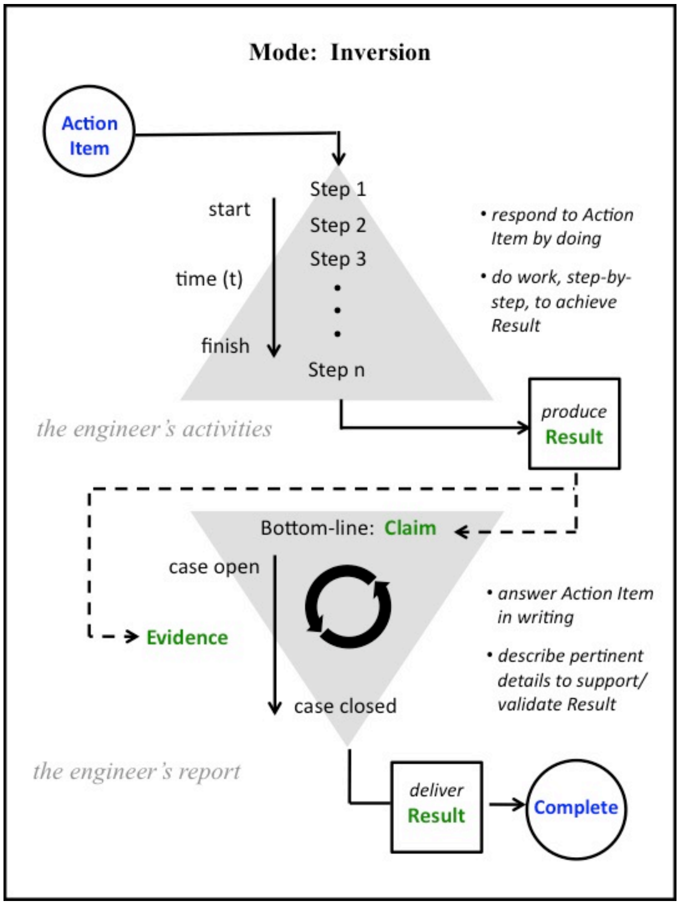

Figure 4--Algorithm to Report Project Status (Response to an Action Item)

The assessment process for the second round of test teaching in the writing class for engineers was guided by a third party, an assessment analyst assigned to the project by the university's office of the provost. The analyst recommended that initial assessment be strategically focused on one of the three document algorithms—the structure for a project status report/memo/email. Both the writing class and the engineering design class required students to write status report memos, which are challenging to write because they must develop bottom-line-first, rather than in standard, linear, beginning-middle-end progression. Fall 2013, the analyst directed the writing class instructor—as well as the engineering design class professor—to administer a Kirkpatrick Scale 2 pre- and post- anecdotal survey, seeking brief answers to the following prompt, before and after delivery of an instructional module on status report memos in each of the respective classes:

> PROMPT: What would you include in a status report memo, if you were working on an engineering project and your boss asked you to write this type of document?

After the pre-survey round, the analyst did a theme analysis of the pre-survey responses for the design class. A post-survey did not occur in the design class. Both pre- and post- surveys were, however, conducted in the engineering writing class, and a theme analysis was conducted on both of these data sets. (See Table 2, Results, for a complete posting of the Fall 2013 theme analysis.) In the engineering writing class, the instructor also administered a Kirkpatrick Scale 1 pre- and post- class perceptual survey to the engineering writing students. The survey collected scaled response data associated with the class' five overarching SLOs (see Table 3, Results).

Engineering Design Class: During the second round of assessment and test teaching fall of 2013, the writing instructor and mechanical engineering faculty continued their partnership, and once again used a section of the engineering faculty's machine design class as a testing ground. Class-size this time was 54 mechanical engineering juniors/seniors. The goal was to expand and formalize the instructional intervention explored and informally tested during the first trial, the previous spring.

As the students progressed through a multi-step design project, as was the case in the Spring 2013 class, the Fall 2013 students frequently had to report progress made by the students' 3- to 4-person design teams. They did this via status report memos. Once again, the project culminated with the student teams writing a final design project report. To enable effective and efficient progress, also once again, the writing instructor and engineering professor collaborated in the writing of the incremental assignment handouts, formatted as memos from engineering management (the engineering professor and T.A.) to design engineers working on a project (the students). The collaboration ensured that directions for both the engineering tasks and the writing tasks were clear, complete, and linked to targeted metrics.

Paper-grading metrics included the five key grading criteria developed the previous spring, as well as additional metrics embraced by a newly designed paper grading rubric, which featured a hybrid quantitative/qualitative structure (see Appendix for a sample). The rubric was co-developed by the writing instructor, engineering professor, and T.A., with the objective being to make the paper grading process user-friendly for the T.A., relevant and fair for the students, and (on behalf of the dictums of good instructional design) criteria-referenced to *all* assignment-level learning outcomes, without, on the other hand, dissecting the grading process into a tedious onesie-twosie tally.

The instructional materials for the second trial in the machine design class included the handouts from trial one as well as additional materials associated with two customized J.I.T. instructional modules, each 30 minutes long, threaded into design class lecture time. The first module, delivered the third week of the 10-week quarter, provided formal instruction on how to write an algorithm-guided status report memo. The second J.I.T. module, delivered during the fifth week, provided formal instruction on appropriate sentence-level style for engineering writing.

For assessment, as was previously mentioned, the project analyst directed the engineering professor to administer the same Kirkpatrick Scale 2 pre- and post- anecdotal survey as was administered in the Fall 2013 engineering writing class (see Figure 2, Results). And, as was already noted, a full set of pre- anecdotal survey results were collected, but post survey results were not. In an attempt to collect Kirkpatrick Scale 3 data—data that measures students' ability, beyond delta learning, to practically apply learned material—the analyst directed the design class' T.A. to collect sample student memos, submitted before and after the instructional intervention via the J.I.T. modules. The two J.I.T. modules were inserted between the design class' memo 1 and memo 4 assignments. Typically, in this class, student papers are submitted online, and retaining a complete set of memos 1, 2, 3, and 4 is routine. The T.A. received and graded all of the memos. Unfortunately, Fall 2013, archived digital copies of the memo 1 samples were not retained. A complete set of student sample memo 4s were retained.

To get an initial read on impact of the *informal* and *formal* J.I.T. instructional modules on memo writing in the design class, both Spring 2013 and Fall 2013, the engineering writing instructor (this paper's author) assigned a project intern in engineering writing to study the five paper grading criteria and criteria definitions that were developed for report memo grading in a design class. The intern—a mechanical engineering undergraduate possessing exceptional engineering writing skills who was recruited from the university's Integrated Studies/Honors Program—was then directed to use the five metrics to do a first-pass, holistic assessment of sample student papers, compiled for both Spring 2013 and Fall 2013 machine design classes—specifically, the student samples for memo 1 and memo 4.

For scoring, the engineering writing intern used a 4-point-scale rating system, for all five key criteria (completeness, quality, velocity, noise, and packaging). The rating scale was the standard schema: 4=excellent, 3=good, 2=okay/marginal, and 1=inadequate/fail Table 4, Results, showcases the outcome of this preliminary analysis. The project analyst, engineering writing instructor, and engineering design professor are, of course, eager to conduct a deeper-level and more rigorous document quality and document features inventory of all of the student memo samples collected thus far. The next round of data analysis, scheduled to occur later on in the academic year, either late Winter Quarter 2014 or early Spring Quarter 2014, will incorporate trials of the new Fall 2013 hybrid quantitative/qualitative grading rubric (see appendix) and a 6-person review panel of writing and engineering faculty rather than singular T.A. or intern reviewers.

The engineering writing instructor also requested the Fall 2013 engineering design class' T.A. to respond to a post-class, Kirkpatrick Scale 1, perceptual survey. See Table 5, Results, for a record of the survey's five prompts and the T.A.'s anecdotal feedback.

Results

	n=18	Diagnostic, Total Class Score, Number of Occurences, with repeats	Pre-test, Total Class Score, Percent Success, Error I.D.s, no repeats	Post-test, Total Class Score, Percent Success, Error Identificatio, no repeats
1	Missing comma after introductory element	1	63%	71%
2	Vague pronoun reference	1	19%	57%
3	Missing comman in a compound sentence	3	75%	86%
4	Wrong word	22	75%	93%
5	Missing comma(s) with a nonrestrictive element	2	88%	50%
6	Wrong or misplaced verb ending	0	31%	57%
7	Wrong or missing preposition	8	6%	43%
8	Comma splice	8	75%	93%
9	Missing or misplaced possessive apostrophe	0	69%	86%
10	Unnecessary shift in tense	11	31%	64%
11	Unnecessary shift in pronoun	5	44%	86%
12	Sentence fragment	1	44%	93%
13	Wrong tense or verb form	2	56%	93%
14	Lack subject-verb agreement	7	6%	43%
15	Missing comma in a series	3	38%	79%
16	Lack of agreement between pronoun and antecedent	1	6%	100%
17	Unnecessary comma(s) with a restrictive element	0	81%	86%
18	Fused sentence	0	69%	86%
19	Misplaced or dangling modifier	0	50%	86%
20	Its/It's confusion	0	63%	86%
	Individual Scores	4 common errors/paper	10 out of 20 identifications	15 out of 20 identifications

KEY: [cyan] = top three error occurences; [green] = three most missed errors

Table 1–Diagnostic Benchmark, and Pre- and Post- Common Error Identification Data
Engineering Writing Class, Spring 2013

(Results, cont.)

$n^1 = 21$ $n^2 = 54$	**Before** J.I.T. Instructional Module on Status Report Memos		**After** J.I.T. Instructional Module on Status Report Memos	
	Engineering **Writing Class**[1]	Engineering **Design Class**[2]	Engineering **Writing Class**[1]	Engineering **Design Class**[2]
Attribute Category	**Tally**	**Tally**	**Tally (Δ)**	**Tally (Δ)**
Budget	5	10	3 (-2)	not available
Changes (have happened)	6	10	1 (-5)	
Completion (tasks, steps)	18	39	12 (-6)	
Long-term goals (no reference to time)	6	18	2 (-4)	
Problems encountered	16	27	10 (-6)	
Short-term goals (next steps)	13	12	10 (-3)	
Solutions	5	13	3 (-2)	
Timeline / deadline	17	16	7 (-10)	
Front-loaded / bottom-line-first	0	0	11 (+11)	

PROMPT: What would you include in a status report memo, if you were working on an engineering project and your boss asked you to write this type of document?

Table 2–Student Survey, Theme Analysis
Engineering Writing Class and Engineering Design Class, Fall 2013

(Results, cont.)

n = 21	Level 1 (blank slate)	Level 2	Level 3	Level 4	Level 5 (expert)
SLO #1: "I have a general understanding of how engineering communication integrates into engineering practices and why it is an essential core skill for engineering professionals."					
pre-test	1	6	10	4	0
post-test	0	0	3	9	9
SLO #2: "Given a specific writing task, I can assess associated purpose, context, and audience (wants, needs, and level of technicality) and then align and aim message accordingly."					
pre-test	0	2	13	6	0
post-test	0	0	4	13	4
SLO #3: "I can write in an effective, discipline-specific style that conveys messages concisely, clearly, and correctly."					
pre-test	0	2	11	7	1
post-test	0	0	4	11	6
SLO #4: "I can indentify and use common, discipline-specific document structures (e.g., project report, project proposal, and status report memo) in workplace writing tasks."					
pre-test	5	7	8	1	0
post-test	0	0	2	13	6
SLO #5: "I can deliver effective oral presentations that incorporate public speaking best practices, Power Point slides, and multimedia technology."					
pre-test	0	6	8	5	2
post-test	0	0	5	12	4

PROMPT: As of right now, using a scale of 1 to 5 (where 1=blank slate, and 5=expert), please characterize your skills/knowledge related to the following statements:

Table 3–Pre- and Post- Class Comprehensive Evaluation, All Five SLOs
Engineering Writing Class, Fall 2013

(Results, cont.)

CRITERIA	Five Top-level Criteria for Evaluating the Quality of Engineering Status Report Memo	M1, EME 150A Machine Design, Spring 2013, Memo 1 of 4, n=14	M4, EME 150A Machine Design, Spring 2013, Memo 4 of 4, n=14	M1 vs. M4 Δ %, with ***informal JIT***	M4* EME 150A Machine Design, Fall 2013, Memo 4 of 4, n=12	M1 vs. M4* Δ %, with ***formal JIT***
1	Completeness	2.8	3.3	17.9%	3.1	10.7%
2	Quality	2.6	3	15.4%	3	15.4%
3	Velocity	3	3.1	3.3%	2.9	-3.3%
4	Noise	3	3.4	13.3%	3.2	6.7%
5	Packaging	2.5	2.9	16.0%	2.7	8.0%

note: 4-point scaling, where 4=excellent, 3=good, 2=okay/marginal, and 1=inadequate/fail

Table 4 – Preliminary Assessment of Writing Skill Development:
Four-paper Progression of Status Report Memos, with Informal vs. Formal JIT Module threaded between Memo 1 and Memo 4

Engineering Machine Design Class, Spring 2013 and Fall 2013

(Results, cont.)

The T.A.'s prompts	The T.A.'s anecdotal feedback
1) What was YOUR general observation (macroscopic point of view) about the students' overall paper quality--the status report memos--before and after we inserted threaded "Just in Time" (J.I.T.) instruction about engineering writing into the machine design class?	Night and day difference. A lot of the students had similar problems, which I emailed to [...] and [...] at one point, and both of you talked about these problems class. The most obvious difference to me can be seen between the first project memo and the later status memos / final report.
2) What were some specific changes (microscopic point of view) you observed in the papers, before and after.	Before, some of the lower-quality papers were very sloppily-done. By this I mean it seemed as though the students just thought "I'm writing an engineering paper, so I don't have to have any quality in my spelling, grammar, or sentence structure." There were a lot of typos, and sentences that were difficult to read. To me, this was more of a problem than the formatting, although that improved over time as well.
3) Was there anything about the threaded instruction and complementary tools (e.g., new rubrics) that made it easier (or harder) for you in doing your grading tasks?	It made it easier for me to quantify the quality of the writing. More importantly, it made it easier for me to give students feedback on their writing--you can definitely see the improvement in the writing from the earlier grades.
4) Was there anything about the threaded instruction and complementary tools that you feel, by exposure, has made YOU a better engineering writer yourself?	It gave me a more technical understanding of common problems seen in engineering. I've usually been a more competent writer than many of my peers in the engineering world, but I've really only written by "feel" (meaning that if it sounds good when I read it, I assume that it's decent enough). The additional threaded instruction helped me to identify what makes a sentence "feel" right.
5) Next time around, how can we improve the system--make it better--more efficient, more consistent, more user friendly for you, the T.A., and also for the students?	I think for the students, it would help to give them the rubrics before the assignments are due. It would also probably be good to include the threaded instruction earlier in the quarter.

Table 5–T.A.'s Reflections, Post- J.I.T. Module on Status Report Memos
Engineering Design Class, Fall 2013

Conclusions and Recommendations

The author acknowledges that all data showcased in this paper's Results section is the product of first-iteration "field testing," and because of this, at best, the data sets indicate whether specific instructional methods test taught in this study show promise, or not, and should be advanced through further refinement, and more rigorous and larger-scale trials, or not. The author enthusiastically asserts the general conclusion: *system shows promise*.

Relative to the first trial testing of the math-based writing instruction system—specifically, *sentence algebra*—in the author's writing class for engineers, Spring Quarter 2013, the *Table 1–Diagnostic Benchmark, and Pre- and Post- Common Error Identification Data* project results do show a uniformly positive trend. In their ability to identify occurrences of Lunsford's common errors, the students' average individual score improved from 10 out of 20 at the beginning of the quarter, to 15 out of 20 at the end. The data also revealed what were, for this group of 18 engineering students, the common errors that occurred most frequently in the students' diagnostic papers (#4, #10, and #7-#8 tie), along with what common errors continued to vex the student writers, even after instructional intervention, in the post-class editing exercise (#6, #5, and #7-#14 tie). Next time around, of course, it would be prudent to administer a post-class diagnostic paper, in addition to the post-class editing exercise.

Relative to first trial testing of the new system in the engineering machine design class Spring Quarter 2013, as stated earlier, the work done by the author and the author's engineering professor partner was preparatory and "informal" in nature. The five paper grading criteria distilled by the partnership, though not loaded into a formal rubric at this stage, were noteworthy to the writing instructor, the engineering professor, and the class' T.A. The class T.A., at the time, was using a grading instrument developed around a uniformly holistic method, and the T.A. deemed it non-user-friendly. Although not immediately analyzed, digital copies of student sample memo 1s and memo 4s were archived by the course's online management system. This Spring 2013 data was analyzed subsequently, Fall 2013. Table 4, Results, shows mild, yet uniformly positive, improvement trends for writing skill building associated with the education intervention between the memo 1 and memo 4 assignments. Although for the *velocity* criterion, there was only a 3.3% increase, from average score of 3 out of 4 to 3.1 out or 4, for the other four criteria, increases were all around 15%, ranging from 13.3% (*noise*) to 17.9% (*completeness*).

The skill building improvement that resulted from the *informal* J.I.T. intervention was noteworthy.

Relative to the second trial testing of the math-based writing instructional system in the author's writing class for engineers, Fall Quarter 2013, *Table 3–Pre- and Post- Class Comprehensive Evaluation, All Five SLOs* reveals a sweep of progress toward mastery of the class-level student learning outcomes. Whereas at the beginning of the writing class, students tended to self-evaluate competency in all five SLOs with averages peeking at Level 3, at the end of the class, the averages uniformly moved up to Level 4, with a significant number of students in the class ambitiously ranking themselves Level 5, Expert. Also at the end of the class, none of the 21 students rated themselves low, at Level 1 or Level 2, for any of the five SLOs. This was not so at the beginning of the class. Most profound perhaps, at the end, 13 students ranked themselves Level 4 and 6 students ranked themselves Level 5, Expert, for SLO #4, the outcome associated with discipline-specific document structures, the facet of the system that received test-teach emphasis that quarter.

Further noting that for this round, the project placed emphasis on document algorithms rather than sentence algebra, key second-trial data for *both* the writing class *and* the engineering class appear in *Table 2–Student Survey, Theme Analysis.* Because the post-J.I.T. data is missing for the engineering design class, nothing useful can be concluded here. The pre- and post- theme analysis for the engineering writing class yielded somewhat unexpected results. For every attribute except one, number of instances decreased, with negative deltas ranging from 17 to 7 at -10 for "timeline/deadline" and 5 to 3 at -2 for "budget." The one positive delta was significantly large, 0 to 11 at +11 for "front-loaded/bottom-line-first." Perhaps the results are not so surprisingly upon further consideration. The J.I.T. on status report memo writing emphasized "bottom-line-first" structure as a top-level structural feature. Apparently, the students followed suit and reiterated this as a learning, and then assigned less emphasis toward naming the other features because the students were going for a "best answer."

In the second trial of the machine design class, since there was no memo 1 student sample data with which to compare Fall 2013 memo 4 (M4*) data, Table 4 shows the memo 4 data versus Spring 2013 memo 1 (M1) baseline. This is probably a reasonable reference point for looking at "rough-cut" preliminary differentials. What is most remarkable here is that, Fall 2013 memo 1 data missing or not, the Fall 2013 memo 4 skill improvement percentages displayed to be generally less than those logged for Spring 2013 memo 4. In fact, for one criterion, velocity, the

Fall 2013 change from memo 1 to memo 4 was slightly negative (-3.3%). The good news is that both J.I.T. interventions, informal Spring 2013 and formal Fall 2013, do show evidence of positive impact. Next test teaching trial, the formal J.I.T. will need to be further optimized, and more strongly informed by the initial informal strategy—more compact lecture and fewer handouts, versus longer J.I.T. lecture and additional, perhaps diluting, materials.

Finally, relative to the second trial testing in the engineering design class, the author assigns much credence to *Table 5 – T.A.'s Reflections, Post- J.I.T. Module on Status Report Memos*. Although one engineering T.A.'s reflection on the attributes, merits, and possible extensions of the subject system cannot be viewed as in any way conclusive, what the author liked very much about the Fall Quarter 2013 T.A.'s post-class comments were that the comments echoed the notion of promise mentioned earlier in this section. In this study, initially at least, threading J.I.T. instructional modules on discipline-specific writing into an engineering design series class does appear to be a device that teaches engineering writing *not only* to students in the class *but also* to the graduate student T.A. who supports the class. What's more, threaded J.I.T.s also appear to improve paper grading quality and to reduce paper grading time, since the system ties instructional outcomes to an objective, more quantitative than qualitative, rubric. The author looks forward to continuing this project throughout the 2013-2014 academic year, and, beyond that, into future expansions of the project, which could include broader adaptations in the STEM disciplines and in ESL instruction of math-based thinkers.

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Appendix

(a) Twenty Essential Features of an Engineering Document

(b) Ten Things about Engineering Writing that Engineering Students Should Know

(c) Five Tips for Writing Excellent Memos

(d) Status Report Memo Rubric, Machine Design Class

Twenty Essential Features of an Engineering Document
(to apply where useful and applicable)

beginning

1. establishes the document's topic and scope.
2. establishes document significance.
3. situates [providing pertinent background] and/or "baselines" subject engineering activity.
4. establishes document objective [and writer's connection to objective].
5. establishes target outcomes (objectively and quantitatively, # % $).

middle

6. describes/explains object of engineering activity process(es) used to advance activity.
7. records experimental setups and data collection methods so they are (or assert to be) reasonably "reproducible and repeatable."
8. showcases outcome-referenced results using "best choice" vehicles (text, graphics, or combination) to accent key points and outcome alignment (or misalignment).
9. fulfills implicit contracts with readers associated with graphics.

end

10. presents win-win positions (as objectively and quantitatively as possible) that consider the wants/needs/level of technicality of project doer, project manager, and project stakeholder.
11. enters into data-driven arguments that yield complete answers to document objective.
12. uses quantitative baseline and outcome criteria to hinge data-driven argument.
13. shows foresight and insight by extending beyond just answering (i.e., citing conclusions and recommendations) the project objective, and looking at next logical steps and possible bonus outcomes and spin-offs.

throughout

14. recognizes and aligns message with target audience(s).
15. anticipates report audiences' objections and preemptively defuses them.
16. strives for a confident, convincing, and professional tone.
17. strives for maximum reader uptake "velocity" and minimal interference "noise" by building document out of concise, clear, and correct sentences (and paragraphs).
18. uses effective headings and user-friendly modularization, as well as "best choice" typography to maximize velocity and minimize noise.
19. advances a coherent and cohesive discussion that regularly partners assertions and claims with viable, credible evidence.
20. accents textual discussion with complementary examples and illustrations.

Ten Things about Engineering Writing that Engineering Students Should Know

facts

1. To be successful in any engineering career, both in industry and in research/academe, engineering professionals need to be proficient workplace writers. Most engineers spend 20-40% of their work time writing and speaking, and managers spend well over 40% (Beer & McMurray 2009).

2. In spite of the above, most engineers *don't like to write* (more than they like to do engineering and number crunching).

3. The stereotype that left-brain thinking engineers, in general, lack the capability to become excellent writers is bogus. A number of famous writers have backgrounds in engineering, not English Literature—e.g., Fyodor Dostoevsky, Robert Louis Stevenson, Henry David Thoreau, and Norman Mailer (Moran 2010).

obstacles

4. The educational system is designed to teach writing using a holistic (top-down) method. On the other hand, math-based classes, the bread and butter of engineering, are taught using a linear, climb-the-staircase (bottom-up) method—i.e., first the building blocks, then the building.

5. The contemporary writing system calls upon engineers to apply critical thinking skills in the domain of the language arts without mastery of the arithmetic (and algebra) of language equations.

6. Writing skill, just like any skill, demands practice in order for the practitioner to be able to execute the skill quickly, nimbly, precisely, and accurately.

solutions

7. Engineers can choose to approach professional development as writers like they do an equipment malfunction: troubleshoot to root cause(s), determine the necessary components and repairs, and then acquire the necessary components and do repairs.

8. Historical data indicates that most writing problems can be successfully repaired with the following components and procedures: learn the arithmetic of sentences and how to avoid common errors, develop the ability to write messages that align with the target audience's wants/needs/technicality, learn the algorithms behind standard document structures (e.g., memos, reports, project plans, etc.).

9. Identify and make good use of all professional development opportunities in the area of engineering writing—e.g., the writing component of EME 150A.

10. Be smart and be successful. Assign the same level of professional accountability to excellence in writing and as you do to excellence in engineering.

sources: Beer, David, and David McMurray, *A Guide to Writing as an Engineer*, 4th ed., John Wiley, 2009
Moran, Tom, *Engineers Can Write!*, 1st ed., IEEE Press, 2010

Five Tips for Writing Excellent Memos

Tip #1

Unlike business letters and also emails, memos begin with a sentence and end with a sentence. Thus, the text below the memo's header does NOT include a salutation ("Dear So-and-so:") nor does the text below the memo's body include a complimentary closure ("Sincerely"/signature/"Writer's Name").

Tip #2

The sentence that begins the memo should get down to business right away and state the memo's bottom-line (i.e., what is it, in sum, that the writer wants/needs/has to offer). When it comes to memos, boring trumps fancy. When at a loss for how to start a memo, keep it simple. Just type, "The purpose of this memo is...[and keep going]." Likewise, the sentence that ends a memo also has a singular objective: to establish closure, to signal *end-of-message*. The ending's purpose is NOT to re-hash and summarize what's just been said (why bother? it's just been said!). Ending sentences like "Thank you." or "I look forward to working on the next phase of the project.", though not fancy, gets the job done.

Tip #3

Typographically, a memo's text is formatted in single-spaced blocks, flush left, ragged right, and with no tab at the beginning of paragraphs. The text should be double-spaced between paragraphs. Do not format the blocks of text with flush-right vertical margins. Ragged right is easier on the reader's eyes and makes for a quicker to read.

Tip #4

Keep memos as short as possible. Whenever possible, strive for one or two pages of text (one page preferred). Avoid large blocks of single-spaced text. They put readers' eyes on overload and cause message uptake to slow down, even stall. In memos, the ideal paragraph length is one to eight lines. Paragraph frequently to intersperse black text regularly with bands of white space. Worry less about "topic sentences" and more about "logical breaks."

Tip #5

Build paragraphs out of concise, clear, and correct sentences. Because memos are relatively short documents, composing a memo requires a writer to produce significantly fewer sentences than required by a formal report or proposal. That's the good news. The bad news is that more responsibility and individual emphasis is placed upon each sentence in a short document. Thus, when sentence-level mistakes occur they telegraph glaringly. As a final step, a writer should read her/his memos slowly out loud before s/he hits *send*. This puts into play the writer's "ear knowledge" of English, in addition to the writer's "head knowledge" of English.

Note: here's a trick to go along with tip #5: during the final, read-aloud test, assume that anything that sounds clunky IS CLUNKY and that it needs to be fixed. And even if you, the writer, do not know theoretically (grammar-wise) what's wrong, if you fiddle around with the sentence and get it to sound better when voiced aloud, then chances are that this version IS better. Trust your "ear knowledge" and go with it!

Machine Design: Status Report Memo 4 WRITER'S NAME(S): ____________________________
Grading Rubric (100 point scale)

____

Grade: ______

____

	Qualitative Feedback	Quantitative Scoring
Content (Quality of Engineering Design)		[60]
Fulfills on Deliverables (40 pts max.)		_____
• updated description of design/components/materials	_____	
• updated geometry of structural components (figures)	_____	
• calculations for strength and fatigue criteria	_____	
• creativity/energy/professionalism ("X" factor)	_____	
Technical Rigor and Completeness (20 pts max.)		_____
• text descriptions and discussions	_____	
• technical quality of calculations	_____	
Delivery (Quality of Document Design)		[40]
Format (20 pts max.)		_____
• typography of text (chunked, correct justification)	_____	
• clarity of sketches/figures	_____	
Writing (20 pts max.)		_____
• bottom-line first structure	_____	
• concision	_____	
• clarity	_____	
• correctness	_____	
TOTAL (100 pts max.)		_____

Qualitative Key: √√ = excellent √ = good ○ = marginal x = inadequate