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HELPING STUDENTS COMMUNICATE TECHNICAL MATERIAL

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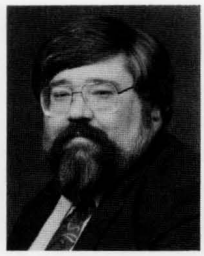

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Communication skills are important to engineers and to their employers, but the communication skills of graduates in engineering are seldom as good as their technical skills.[1-3] In most engineering curricula, laboratory and design reports provide an opportunity to help students learn how to communicate technical material.[4-8] We miss that chance, however, if we evaluate the technical merit of students' reports but ignore how well they are written.

The least we can do is to identify those places where the reports communicate poorly, require that the students rewrite them, and hope for improvement. The best we can do is to show students *why* their reports communicate poorly and *how* to make the required improvements. This article will outline a method of showing students how to write clearly and will explain the principles behind that method.

BAD WRITING, GOOD ADVICE

Some writing problems are easy to spot and easy to fix: errors in spelling, grammer, and punctuation; problems in literature references; tables and figures that lack legends or are not discussed in the text; etc. Though important, these problems alone may not determine how well a report communicates. By focusing only on them, we do not help students to master a skill crucial to employers and working engineers—the ability to communicate technical information in words as well as in numbers.

One key to effective communication is *style*—the sentence forms in which students express technical information. But when it comes to problems of style, some of us have little to say. We might tell students that their writing is unclear, indirect, abstract, convoluted, flowery, awkward, etc., and advise them to be "clear and direct" or to "write as you speak." While such comments may be accurate, they are far too general to be of much use. In order to improve as writers, students need to know both what causes their writing to be unclear or convoluted and what they must change in order to make it clear and direct.

Writing researchers have recently developed better and more useful methods of responding to students' writing—methods based on research on how people process and understand what they read. Much of that work can be found in the book *Style,*[9] which presents a simple, but powerful, method of teaching style. The research base of the book can be found in Colomb and Williams,[10] and the methodology developed by those authors is summarized and applied to scientific writing by Gopen and Swan.[11] In this paper we will describe its most useful tools and show how they can be used by teachers to help students improve their communication skills.

The First Principle of Readable Writing

Express important actions as verbs, and the characters associated with those actions as the subjects of those verbs.

Consider the following "Conclusions and Recommendations" section of a senior design report that is technically sound but poorly written in typical ways.

> *From the study done regarding this process a fairly firm conclusion may be stated affirming the feasibility of Case 1 in which only the n-butane rail imports are replaced. Because no modifications are made to the gas concentration unit itself, the specifications predicted may be obtained with very little error . . . .*
>
> *For Case 2, in which all of the butane rail imports are to be replaced, a feasible plan, which involves the purification of the excess n-butane entering with the required amount of isobutane in the NGL, has been developed. The introduction of the NGL stream was made into the feed to the butane splitter. The desired quantity of isobutane from the top of the column was achieved by this method. The bottoms from the butane splitter would then be sent to a packed column which has been designed to separate pure n-butane which meets industry specs. The bottoms from the new column would then be returned to the blending butane product stream which would then be producing an extra 10,000 Bbl/yr.*

The style of this passage is typified by the sentence

1a. *The introduction of the NGL stream was made into the feed to the butane splitter.*

In order to see the distinctive features of the sentence 1a, compare the following three variations on a theme:

2a. *The heating of the reaction mixture occurred after the introduction of the catalyst.*

2b. *The reaction mixture was heated after the catalyst was introduced.*

2c. *She heated the reaction mixture after she introduced the catalyst.*

Sentences 2a-c tell roughly the same story, but most readers find 2a less clear and readable than either 2b or 2c. Between 2b and 2c, most readers find 2c slightly more readable, but readers with technical backgrounds are perfectly comfortable with 2b. Note that 2a is most similar in feel to 1a.

These reactions are uniform among readers because these examples demonstrate key features of the way we understand sentences. Sentences, even the most technical ones, tell stories. With rare exceptions, sentences have two necessary elements: subjects and verbs. Similarly, stories have two necessary elements: characters and actions. Readers

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find that sentences are clearer, more direct, less abstract, less complex—in short, more readable—when the story elements line up with the sentence elements: characters as subjects and actions as verbs.

In 2b and 2c, key actions are expressed as verbs: *was heated . . . was introduced* and *heated . . . introduced*. Subjects are characters: *reaction mixture . . . catalyst* and *She . . . she*. In 2c the character is a person, while 2b treats the experimental materials *reaction mixture* and *catalyst* as characters. Although sentences are usually clearer when the subject/character is a person (preferably the agent or "doer" of the action) readers with technical backgrounds are accustomed to stories about such things as reaction mixtures and catalysts, and they generally prefer not to have their stories focus on the persons who do the heating and introducing.

In both 1a and 2a, however, the actions are expressed not as verbs, but as nouns. As a result, readers must struggle through the grammar in order to unpack the story. The 1a and 2a sentences are built around nouns made from verbs (often by adding a suffix: -tion, -ness, -ence, -ity, or -ing). These nouns, called *nominalizations,* are usually a problem because they steal important action from the verb, forcing writers to use a weak or empty verb. Students tend to overuse nominalizations, and they need our feedback in order to distinguish between those that are necessary technical terms and those that steal action from the verb.

So now, for sentences 1a and 2a we can

- **locate the problem**
- **explain to the writer what caused the sentences to seem to us unclear, indirect, and difficult**
- **tell the writer how to make them more readable:**

> "Sentences 1a and 2a are unclear because the actions in the sentences are expressed as nouns rather than verbs. As a result, the key sentence elements—subject and verb—do not correspond to the key story elements—character and action. You can make the sentences more readable if you change the nouns expressing actions into verbs (*e.g.,* introduction into introduce) so that the subjects express characters and the verbs express actions."

The Second Principle of Readable Writing

Keep subjects as short as possible so that sentences move quickly from a short, specific subject to an action verb.

Once again, we begin with sentences that tell roughly the same story:

3a. *The mixture, because it was vigorously stirred and the temperature was maintained above 200 Deg. C, reacted rapidly.*

3b. *The mixture reacted rapidly because it was vigorously stirred and the temperature was maintained above 200 Deg. C.*

While neither sentence is unreadable, most readers find 3b more readable than 3a, and all readers begin to struggle in passages with lots of sentences like 3a. In this case, the story elements (character and action) do line up with the sentence elements (subject and verb). But in 3a the story in the main clause, *The mixture . . . reacted rapidly,* is interrupted by all the rest of the sentence. Readers must process all of the intervening information before they achieve the subject-verb closure that holds the story together. In 3b, the subject-verb/character-action pairs are all joined, so that we are able to process the story in three discrete chunks connected by logical markers (*because* and *and*).

Technical writers are particularly prone to write sentences with long, complex subjects or with information intervening between subject and verb. Since they so often use passive verbs in order not to focus on the persons who perform the actions, technical writers often push the verb toward the end of the sentence. Here is an instance from our long example:

4a. *For case 2, in which all of the butane rail imports are to be replaced, a feasible plan which involves the purification of the excess n-butane entering with the required amount of isobutane in the NGL, has been developed.*

In this sentence, readers are forced to process quite a lot of information before they attain subject-verb closure.

Here too, the method allows us to locate the problem, explain to the writer what caused the sentences to seem to us unclear, indirect, and difficult, and tell the writer how to make them more readable:

"Sentence 4a is unclear because its subject is long and complex. As a result, readers have to process too much information before they can connect the key sentence elements, subject and verb. You can make the sentence more readable if you move quickly from a short, specific subject to an action verb."

The Third Principle of Readable Writing

Sentences should begin with old information and end with new information.

It is not enough that our students write sentences that are individually clear. The sentences also have to "flow" together into a story that is coherent as a whole. Sentences flow together because readers use the information they have already read and remembered to look forward to the next sentence. If the next sentence surprises them by beginning with something they did not expect, they feel a little jolt of disorientation. If the sentences in a passage consistently surprise readers, their feeling of disorientation builds until it becomes hard to follow the story.

In order not to surprise readers, sentences should begin with something that places them in the context of the discussion: they should begin with information that readers will already have read and remembered. This familiar information can be something in the immediately previous sentence or any information that is assumable or expectable, given what has come before. In short, sentences should begin with *old information.*

Once again, we find an instance in our long example:

5a. *The introduction of the NGL stream was made into the feed to the butane splitter. The desired quantity of isobutane from the top of the column was achieved by this method.*

These sentences do not "flow." They feel disjointed, even after we eliminate the nominalization from the first sentence and connect the subject and verb in the second sentence:

5a´. *The NGL stream was introduced into the feed to the butane splitter. The desired quantity of isobutane was achieved from the top of the column by this method.*

Few readers of the first sentence in 5a or 5a´ would expect the second sentence to begin with "The desired quantity of isobutane." Isobutane had been mentioned earlier, but not in a way that readers would expect it to return. In the second sentence, the phrase that most strongly refers backward is "this method." Although "method" has not occurred before, it is nevertheless old information, because the whole passage has been describing the method.

The old-before-new principle has even greater

effect in longer passages, as in these examples:

6a. We should consider employing multiple reactors in parallel before we finalize our design. If one reactor shuts down, the other reactors can operate. For this reason, the parallel arrangement is flexible. Identical controllers can be used on all the reactors, thus making the parallel arrangement easier to control than a series arrangement. Plant operators have more difficulty in understanding series operation than parallel operation.

6b. Before we finalize our design, we should consider employing multiple reactors in parallel. The parallel arrangement is highly flexible; if one reactor shuts down, the others can continue to operate. Parallel reactors are easier to control than reactors in series because all of the parallel reactors utilize identical controllers. Parallel operation can be understood by the plant operators more easily than series operation.

7a. We should consider employing multiple reactors in series before we finalize our design. More control equipment but less volume at a given conversion are required for a series of reactors as compared to a single reactor. Three reactors in series would save us about $1,000,000 in fixed capital, at our required conversion of 90 percent. Higher quality separators could be purchased with the saved capital.

7b. Before we finalize our design, we should consider employing multiple reactors in series. A series requires more control equipment than a single reactor but requires less volume for the same conversion. At our required conversion of 90 percent, three reactors in series would save us about $1,000,000 in fixed capital. These savings could be invested in higher quality separators.

In both pairs, the second passage feels "tighter" and more organized because each new sentence begins in a way we expect. In 6b, each sentence returns to the same idea ("parallel"). In 7b, the sentences begin differently, but with an idea from the immediately previous sentence. Both arrangements create an organized flow through the passage.

RESPONDING TO STUDENTS' WRITINGS

Thus far, we have described the methodology in terms of an interrelated set of principles. Once teachers understand the principles, the methodology can be implemented through a series of simple decision procedures. These procedures focus on the first five or six words of the sentence, because the three principles work together to put the key elements there. If the first several words of a sentence include a subject that names a character, a verb that expresses a key action, and some old information, then that sentence is likely to be in a readable style.

What follows is a method of responding to the style of student writing before you require a revision. (It is equally useful as a way to edit our own work.) At first the method might feel counterintuitive—especially if you usually start reading, red pen in hand, marking as you go. In the long run, however, the method allows us to mark those problems that matter most and to give students useful feedback.

- Read once, very quickly, for an overview. If the report is long, skim just the major sections. The goal of this step is to determine the overall story line and to run a first check on the technical merit of the report. Do this quickly, without making any marks on the page.
- Check that the report has the right sections and the right results in the right places. If data tables or figures are especially important to the results, check them now. Comment on any problems.
- Read through the report. Let the "feel" of the prose, more than your understanding, be your guide. (Because you know the material so well, you can often understand even poorly written passages, supplying from your knowledge the information and connections that students leave out or misstate.) Whenever you feel that you are beginning to work too hard to read a passage, slow down and give it the six-word test.
- The six-word test: Check the first four to six words of each sentence (ignore short introductory phrases). The first several words should include
  - a short, specific subject naming a character
  - a verb expressing a key action
  - old information that sets a context for the rest of the sentence

  If a sentence fails the test, especially if it begins with a nominalization that is not used as a term of art, the sentence is very likely to violate the principles.
- Comment on passages or sentences that violate the principles. Don't mark up the page too much; if there are many problems, comment only on the most important ones. Your comments can take any form that makes you comfortable, but it is generally best to give the student something to do: 1) analyze a portion of a problem passage on the page, and then direct the student to use the six-word test to check the rest for him- or herself; or 2) pick out the problem element in a sentence or passage and suggest a specific kind of change (*e.g.,* "Make this word a verb" or "Make sure your sentences begin with old information"). If you don't

trust the student to be able to make the change and you have the time, you can edit the sentence or passage and comment on the change you made (*e.g.,* "This is clearer with X as a verb").

- If you have the time and energy to spare and you have not already made many comments, you can check grammar, punctuation, spelling, etc. Unless students have very serious problems, these comments will be less important in helping them to communicate effectively. Yet correctness does count, and some teachers believe that students ought to be held to industry standards. It is generally better to pick out a problem and require the student to fix it rather than to fix it yourself.

HOW STUDENTS RESPOND

One of the authors (Ernst) introduces the above principles and report writing in general in a technical economics course, a prerequisite to the senior capstone design course. The students are required to submit a one- to three-page report every other week, usually in the form of a letter discussing in detail an assigned homework problem—its solution and the implications of the solution. Each report is graded on how well the student communicates the information. If the report is poorly written, the writing style is checked and appropriate comments are written in the margin as described above. Students are given a chance to revise unsuccessful reports.

We have been pleased with the results of this process for two reasons: 1) when it is applied to reports assigned early in a quarter, most students who initially submit poor reports produce well-written reports after only one revision, and 2) toward the end of the quarter, most students routinely submit reports that do not need revising.

For one assignment, students were asked to revise a report previously written by another student—in this case the "Conclusions and Recommendations" section which we discussed earlier. Here is one of the best revisions:

In Case 1, only the n-butane rail imports are to be replaced by NGL. We have developed a feasible plan, under which NGL would be transferred directly to the blending butane product stream, yielding a combined product which meets specification . . . .

In Case 2, all of the butane rail imports are to be replaced by NGL. We have developed a feasible plan, under which the NGL would be fed to the butane splitter, where iso-butane would be removed as overhead at the desired rate. The splitter bottoms would be fed to a new packed column, designed to produce a pure n-butane overhead stream which meets industry specs. The column bottoms would be returned to the blending butane product stream at a rate that would increase production by 10,000 Bbl/yr.

Often, students find it necessary to add information as they revise the original work, which illustrates an additional feature of these principles: they serve as a mental discipline that improves the quality of students' thinking. While any well-designed writing assignment can help students consolidate and improve their knowledge, students get an additional boost by writing and revising in accord with these principles. Because the principles focus students on the key elements of the story they have to tell, they help students to think through those stories and discover missing information or gaps in their logic. When students adhere to the principles, they are encouraged to be complete, precise, and logical. When teachers adhere to the principles and follow three easy steps (locate the problem, explain what caused it, explain how students can fix it), the students' gain is threefold: they understand their own research and its results more fully, they communicate their results to us more effectively, and most of all, they learn how to do better next time.

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