How To Write a Scientific Paper

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Editor's Note: Would anyone have the chutzpah to claim that only "scientists" have problems with technical writing? Mr. Day's literate use of humor makes his do's and don'ts of scientific paper preparation easy to take, and to remember. In place of "scientist," read "engineer."

Abstract—The well-written scientific paper has two essential ingredients: organization and appropriate language within that organization. The component parts of a scientific paper are reviewed: Title, Abstract, Introduction, Materials and Methods, Results, Discussion, Acknowledgment, and Literature Cited; and, with quoted material, inappropriate language use is illustrated.

SCIENTIFIC writing is primarily an exercise in organization. A scientific paper is highly stylized, with distinctive and clearly evident component parts. Each scientific paper should have, in proper order, its Introduction, Materials and Methods, Results, and Discussion. Any other order will pose hurdles for the reader, and probably the writer.

The well-written scientific paper has two essential ingredients: organization and appropriate language within that organization.

Although the proper organization of a scientific paper is relatively simple, let us review the component parts, one by one.

And, along the way, let us keep emphasizing language, because it is in this area that most scientists have trouble.

Reprinted with permission from *ASM News*, vol. 41, no. 7, pp. 486-494, July 1975.

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If scientific knowledge is at least as important as any othe knowledge, then it must be communicated, effectively, clearly in words of certain meaning. The scientist, to succeed in thi endeavor, must therefore be literate.

David B. Truman, Dean of Columbia College, said it well "In the complexities of contemporary existence, the specialis who is trained but uneducated, technically skilled but cu turally incompetent, is a menace."

Although it is recognized that the ultimate goal of scientifi research is publication, it has always been amazing to me tha so many scientists neglect the responsibilities involved. scientist will spend months or years of hard work to secure h data, and then unconcernedly let much of its value be lo because of his lack of interest in the communication proces The same man who will overcome tremendous obstacles t carry out a measurement to the fourth decimal place will b in deep slumber while his secretary is casually changing h micrograms per milliliter to milligrams per milliliter and whil the printer slips in an occasional pounds per barrel.

Language need not be difficult. In scientific writing, we sa "The best English is that which gives the sense in the fewe short words" (a dictum printed for some years in the "I structions to Authors" of the *Journal of Bacteriology*).

Justin Leonard, assistant conservation director of Michiga once said: "The Ph.D. in science can make journal edito

quite happy with plain, unadorned, eighth-grade level composition" (*Bioscience*, Sept. 1966).

The favorite type of verbosity that afflicts authors is "jargon." This syndrome is characterized, in extreme cases, by the total omission of one-syllable words. Writers with this affliction never "use" anything–they "utilize." They never "do"–they "perform." An occasional author will slip and use the word "drug," but most will salivate like Pavlov's dogs in anticipation of using "chemotherapeutic agent." Who would use the three-letter word "now" when he can use the elegant expression "at this point in time?"

Most of us would say "hospital-acquired infection" but the pedant would say "nosocomial infection." One such author got his just desserts when an undetected typographical error resulted in the published statement that his marvelous new drug was effective against "nosocomical" infections.

This reminds me of the plumber who wrote to the Bureau of Standards saying he had found hydrochloric acid good for cleaning out clogged drains. The Bureau wrote back: "The efficacy of hydrochloric acid is indisputable, but the corrosive residue is incompatible with metallic permanence." The plumber replied that he was glad the Bureau agreed. The Bureau tried again, writing: "We cannot assume responsibility for the production of toxic and noxious residues with hydrochloric acid and suggest that you use an alternative procedure." The plumber again said that he was glad the Bureau agreed with him. Finally, the Bureau wrote to the plumber: "Don't use hydrochloric acid. It eats hell out of pipes."

Should we liken the scientist to a plumber, or is the scientist perhaps more exalted? With the Doctor of Philosophy degree, should the scientist know some philosophy? I agree with John W. Gardner who said: "The society which scorns excellence in plumbing because plumbing is a humble activity and *tolerates shoddiness in philosophy because it is an exalted* activity will have neither good plumbing nor good philosophy. Neither its pipes nor its theories will hold water" (*Science News*, vol. 2, p. 137, Mar. 1974).

Let me now try to define what a scientific paper should be, and how it should be prepared.

Never having personally written a scientific paper, I am in a good position to speak authoritatively.

Let me start by saying something that is a bit controversial. I take the position that the preparation of a scientific paper has almost nothing to do with writing, per se. It is a question of *organization*. A scientific paper is not literature. The preparer of a scientific paper is not really an author.

In fact, I go so far as to say that, if the ingredients are properly organized, the paper will almost write itself.

Some of my old-fashioned colleagues think that scientific papers should be literature, that the style and flair of an author should be clearly evident, and that variations in style encourage the interest of the reader.

I disagree. I think scientists should indeed be interested in reading literature, and perhaps even in writing literature, but literature and the communication of research results are two quite different processes.

The reporting of scientific data should be done in an organized, meaningful pattern, wherein the component parts will be recognizable quickly and easily to colleagues interested in those data.

Today the average scientist, to keep up in his field, must examine the data reported in hundreds or even thousands of papers. Therefore, it seems obvious to me that scientists, of course, editors must *demand* a system of reporting data that is uniform, concise, and readily *understandable*.

If a scientific paper is to be highly systematized, how do we *do it? Let us now get specific and go through* the procedure, item by item.

Title

First, the *title*. Here is my definition: "The title should be the fewest possible words that adequately describe the content of the paper."

Remember that thousands of people will read the title of a paper, even though only a few may read the whole paper.

Remember also that the indexing and abstracting services depend heavily on the accuracy of the title. An improperly titled paper may be virtually lost, and never reach the audience for which it was intended.

In my experience, a *few* titles are too short. A paper was submitted to the *Journal of Bacteriology* with the title "Studies on *Brucella*." Obviously, such a title is not very helpful to the potential reader. Was the study taxonomic, genetic, biochemical, or medical? We would certainly want to know at least that much.

Many titles are too long. An overly long title is often less specific and less meaningful than a short title. A generation or so ago, when science was less specialized, titles tended to be long and nonspecific, such as: "On the addition to the method of microscopic research by a new way of producing color-contrast between an object and its background or between definite parts of the object itself" (J. Rheinberg, *J. R. Microsc. Soc.*, pp. 373-388, 1896). That certainly sounds like a poor title; perhaps it would make a good abstract.

It also reminds me of a time, back in the days when I was a librarian, when two students were examining the latest additions to the current-journal shelf. One said to the other, "Say, did you read this paper in the *Journal of Bacteriology* on ribosome structure?" The other student said: "Yes, I read the paper, but I haven't finished the title yet."

In titles, be especially careful of syntax. Most of the grammatical errors in titles are due to faulty word order.

A paper was submitted to the *Journal* with the title "Mechanism of Suppression of Nontransmissible Pneumonia in Mice Induced by Newcastle Disease Virus." Unless this author had somehow managed to demonstrate spontaneous generation, it must have been the pneumonia that was induced and not the mice.

If you no longer believe that babies result from a visit by the stork, I offer this title (*Bacteriol. Proc.*, p. 102, 1968): "Multiple Infections Among Newborns Resulting from Implantation with *Staphylococcus aureus* 502A."

Another example I stumbled on one day (*Clin. Res.*, vol. 8, p. 134): "Preliminary Canine and Clinical Evaluation of a New Antitumor Agent, Streptovitacin." When that dog gets

through evaluating streptovitacin, I've got some work I'd like to have him look over.

Incidentally, the abstract of that article revealed that male puppies were used. A better title would have been: "Evaluation of streptovitacin in sons of bitches."

And dogs aren't the only smart animals. A manuscript was submitted to the *Journal of Bacteriology* under the title: "Isolation of Antigens from Monkeys Using Complement-Fixation Techniques."

Abstract

A well-prepared abstract enables readers to identify the basic content of a paper quickly and accurately, to determine its relevance to their interests, and thus to decide whether they need to read the paper in its entirety.

The abstract should 1) state the principal objectives and scope of the investigation, 2) describe the methodology employed, 3) summarize the results, and 4) state the principal conclusions.

It should *never* give any information or conclusion that is not stated in the paper.

It should not exceed 250 words. In other words, the abstract should be designed to define clearly what is dealt with in the paper. Remember, many people will read the abstract, either in the original journal or in *Biological Abstracts* or *Chemical Abstracts*.

Introduction

Now that we have these two preliminaries out of the way, we come to the paper itself. (I should mention that experienced writers usually prepare their title and abstract *after* the paper is written, even though by placement they come first. To settle on a title before the paper is written is like naming a baby before it is born—you may end up with a girl's name for a boy baby.)

The first section of the text proper should, of course, be the Introduction. The rules:

1) It should present first, with all possible clarity, the nature and scope of the problem investigated.

2) To orient the reader, a brief review of the pertinent literature is usually appropriate.

3) The method of investigation should be stated. If deemed necessary, the reasons for the choice of a particular method should be outlined.

4) The principal results of the investigation should be stated. Do not keep the reader in suspense; let him follow the development of the evidence. An O. Henry surprise ending might make good literature, but it hardly fits the mold that we like to call the scientific method.

Keep in mind that your paper may well be read by people outside your narrow specialty. Therefore, the Introduction is the proper place to define any specialized terms or abbreviations which you intend to employ. Let me put this in context by citing a short paragraph from a letter of complaint I once received. The complaint was in reference to an ad which had appeared in the *Journal of Virology*. The ad announced an opening for a virologist at the National Institutes of Health, and concluded with the statement "An equal opportunity employer, M & F." The letter said "You bandy a glib phrase "an equal opportunity employer," which has never been defined; it was evidently designed to encourage members of minority groups to apply for jobs with government contractors, although the contractors then and now employ kin of their owners to be groomed for higher management position and select additional personnel from racially restricted unions The designation "M&F" may mean that the NIH is muscula and fit, musical and flatulent, hermaphroditic, or wants a mature applicant in his fifties."

Materials and Methods

For materials, include the exact technical specifications and quantities, and source or method of preparation. Sometimes it is even necessary to list pertinent chemical and physical properties of the reagents used.

And, again, be careful of your syntax. A recent manuscript described what could be called a disappearing method. The author stated: "The radioactivity in the tRNA region was determined by the trichloroacetic acid-soluble method of Britten *et al.*"

In describing the methods of the investigations, sufficient details should be given so that a competent worker could repeat the experiments.

However, if a method has been previously published in a standard journal, only the literature reference should be given. But I would recommend more complete description of the method if the only previous publication was in, let us say, the *Nairobi Journal of Proctology*.

Finally, do *not* make the common error of mixing some of the Results in this section.

Results

So now we come to the really significant part of the paper, the data. This portion of the paper we call Results.

Contrary to popular belief, you shouldn't start the Results section by describing methods which you inadvertently omitted from the Materials and Methods section.

There are usually two ingredients of the Results section. First, there is usually some kind of overall description of the experiments, providing the "big picture," without, however, repeating the experimental details previously provided in Materials and Methods. Second, we present the data.

Of course, it isn't quite that simple. *How* do we present the data? A simple transfer of data from laboratory notebook to manuscript will hardly do.

Most important, in the manuscript we want *representative* data rather than endlessly *repetitive* data. The fact that you could perform the same experiment 100 times without significant divergence in results might be of considerable interest to your major professor, but *editors*, not to mention *readers*, would prefer a little bit of predigestion.

If one or only a few determinations are to be presented they should be treated descriptively in the text. Repetitive determinations should be given in tables or graphs.

If statistics are used to describe the results, they should be meaningful statistics. Erwin Neter, Editor-in-Chief of *Infection and Immunity*, tells a classic story to emphasize the

point. He refers to a paper which reputedly read: "$33\frac{1}{3}$% of the mice used in this experiment were cured by the test drug; $33\frac{1}{3}$% of the test population were unaffected by the drug and remained in a moribund condition; the third mouse got away."

The results should be short and sweet, with *no* excess verbiage. Although the Results section of a paper is the most important part, it is often the shortest, particularly if preceded by a well-written Materials and Methods and followed by a well-written Discussion.

When the perfect scientific paper is written, if it ever is, the Results section may possibly have just one sentence: "The results are shown in Table 1."

Discussion

This section is harder to define than the others. As a result, it is usually the hardest to write. And, whether you know it or not, *many* papers are rejected by journal editors because of a faulty Discussion, even though the data of the paper might be both valid and interesting. Even more likely, the true meaning of the data may be completely obscured by the interpretation presented in the Discussion, again resulting in rejection.

Many, if not most, Discussions are too long and verbose. As Doug Savile said: ". . . occasionally, I recognize what I call the squid technique: the author is doubtful about his facts or his reasoning and retreats behind a protective cloud of ink" (*Tableau*, Sept. 1972).

What are the essential features of a good Discussion? I would say that there are perhaps six components, as follows:

1) Try to present the principles, relationships, and generalizations shown by the Results. And bear in mind, in a good Discussion, you *discuss*; do *not* recapitulate the Results.

2) Point out any exceptions or any lack of correlation, and define unsettled points.

3) Show how your results and interpretations agree (or contrast) with previously published work.

4) Don't be shy; discuss the theoretical implications of your work, as well as any possible practical applications.

5) State your conclusions, as clearly as possible.

6) Summarize your evidence for *each* conclusion.

In simple terms, the *primary* purpose of the Discussion is to show the relationships among observed facts. To emphasize this point, I always tell the old story about the biologist who trained the flea.

After training the flea for many months, the biologist was able to get a response to certain commands. The most gratifying of the experiments was the one in which the professor would shout the command "Jump!" and the flea would leap into the air each time the command was given.

The professor was about to submit this remarkable feat to posterity via a scientific journal, but he—in the manner of the true scientist—decided to take his experiments one step further. He sought to determine the location of the receptor organ involved. In one experiment, he removed the legs of the flea, one at a time. The flea obligingly continued to jump upon command, but as each successive leg was removed, his jumps became less spectacular. Finally, with the removal of its last leg, the flea remained motionless. Time after time the command failed to get the usual response.

The professor decided that at last he could publish his findings. He set pen to paper and described in immaculate detail the experiments executed over the preceding months. His conclusion was one intended to startle the scientific wo[redacted] *When the legs of a flea are removed, the flea can no lon[redacted] hear.*

Acknowledgment

At this point, we have finished the text of our scientific paper. However, there are two sections which often follow the text, namely, the Acknowledgment and the Literature Cited.

As to the Acknowledgments, I would say that there are usually two possible ingredients to be considered.

First, you should acknowledge any significant help that you received from any individual, whether in your laboratory or elsewhere. Specifically, you should acknowledge the source of special equipment, cultures, or other materials. Furthermore, you should acknowledge the help of anyone who contributed significantly to the work or to the interpretation of the work.

You might, for example, say something like: "Thanks are due to J. Jones for assistance with the experiments, and to R. Smith for valuable discussion."

Of course, most of us who have been around for awhile would recognize that this was simply a thinly veiled way of admitting that Jones did the work and Smith explained what it meant.

Second, it is usually the Acknowledgment wherein you should acknowledge any outside financial assistance, such as grants, contracts, or fellowships. (In these days, you migh[redacted] snidely mention the absence of such grants, contracts, or fellowships.)

Literature Cited

As to the Literature Cited section, I would again say that there are two rules to follow.

First, only *primary* references should be listed. References to unpublished data, papers in press, abstracts, theses, and other secondary materials should not clutter up the Literature Cited. If such a reference seems absolutely essential, it may be added parenthetically in the text.

Second, check all parts of every reference against the original publication, before the manuscript is submitted, and perhaps again at the galley-proof stage.

Take it from an erstwhile librarian-turned-editor, there are far more mistakes in the Literature Cited section of a paper than anywhere else.

Appropriate Language

We have finished an outline of the various components that could, and perhaps should, go into a scientific paper. Perhaps, with this outline, the paper won't quite write itself. But if this outline, this table of organization, is followed, I believe that the writing might be a good deal easier than it otherwise would.

Of course, you still must use the English language (if you [redacted] submit a paper to an ASM journal at least). For some of you, this may be difficult.

If you can only learn to appreciate, as most managing editors have learned to appreciate, the sheer beauty of the simple declarative sentence, you will avoid most of the serious grammatical problems.

Most of us these days don't worry about things like split infinitives, but they can be overdone. I will quote the best one in my collection, from a legal decision of Judge Thomas, who expunged the Grand Jury Report and upheld the 25 indictments of students and faculty after the Kent State murders. Judge Thomas decided that the Grand Jury Report should be stricken because "it would be unreasonable to expect or ask a prospective juror to honestly to promise to completely disregard these findings and to treat the indictments not as proof of guilt but only as an accusation of crime." On the basis of that sentence alone, I would indict Judge Thomas of a far greater crime than anything attributed to the Kent State students.

Some of you, perhaps, couldn't recognize a dangling participle or gerund if you fell over one, but you can avoid such faults by giving proper attention to syntax.

That is not to say that a well-dangled participle isn't a joy to behold, after you have developed a taste for such things. The working day of a managing editor wouldn't be complete until he or she has savored such a morsel as: "Lying on top of the intestine, you will perhaps make out a small transparent thread."

Those of you who use chromatographic procedures may be interested in a new technique reported in a manuscript recently submitted to the *Journal*: "By filtering thru Whatman No. 1 filter paper, Smith separated the components."

Of course, such charming grammatical errors are not limited to science. I was reading a mystery novel, *Death Has Deep Roots*, by Michael Gilbert, when I encountered a particularly sexy misplaced modifier: "He placed at Nap's disposal the marriage bed of his eldest daughter, a knobbed engine of brass and iron."

A Hampshire, England, fire department received a government memorandum seeking statistical information. One of the questions was, "How many people do you employ, broken down by sex?"

The British must have a penchant for this kind of thing. *Publishers Weekly* some time ago announced publication of a new book titled *Dictionary of British Miniature Painters.*

If any of you share my interest in harness racing, you may remember that the 1970 Hambletonian was won by a horse named Timothy T. According to the *Washington Post* account of the story, Timothy T. evidently has an interesting background: "Timothy T.—sired by Ayres, the 1964 Hambletonian winner with John Simpson in the sulky—won the first heat going away."

I really like the *Washington Post*. Some time ago they ran an article titled "Antibiotic-Combination Drugs Used to Treat Colds Banned by FDA." Perhaps the next FDA regulation will ban all colds, and you virologists will have to find a different line of work.

I shouldn't laugh about typographical errors. We have published one or two minor errors in the ASM journals through the years.

Although all of us in publishing occasionally lose slee worrying about typos, I take comfort in the realization tha whatever slips by my eye is probably less grievous than som of the monumental errors committed by my publishin predecessors.

My all-time favorite typo occurred in a Bible published i English during the time of Charles the First. The Sevent Commandment read: "Thou shall commit adultery." I unde stand that Christianity became very popular indeed aft publication of that edition. If that statement seems blasph mous, I need only refer you to another edition of the Bibl printed in 1653, in which appears the line: "Know ye that t unrighteous shall inherit the kingdom of God."

Back to syntax, I walked into a public library and saw a sig reading: "Only low talk permitted here."

Speaking of libraries, I can suggest a new type of acquisitio I once edited a manuscript containing the sentence: "A larg mass of literature has accumulated on the cell walls c staphylococci."

The first paragraph of a recent news release issued by th American Lung Association said: " 'Women seem to be smok ing more but breathing less,' says Colin R. Woolf, M.D professor, department of medicine, University of Toronto. H presented evidence that women who smoke are likely to hav pulmonary abnormalities and impaired lung function at th annual meeting of the American Lung Association." Eve though that ALA meeting was in the lovely city of Montrea I hope that women who smoke stayed home.

While on the subject of women, I will mention a little gram matical parlor game that you might want to try on yo friends. Hand a slip of paper to each person in the group an ask the members of the group to provide any necessary pun tuation to the following seven-word sentence: "Woma without her man is a savage." The average male chauvini will quickly respond that the sentence needs no punctuatio and he is correct. There will be a few pedants among the ma chauvinists who will place balancing commas around th prepositional phrase: "Woman, without her man, is a savage Grammatically, this is also correct. The truly liberate woman, however, and an occasional liberated man, will place dash after "woman" and a comma after "her." Then we ha "Woman—without her, man is a savage."

Slightly rephrasing an item in the *CBE Newsletter*, I offe the following.

THE TEN COMMANDMENTS OF GOOD WRITING

1) Eaçh pronoun should agree with their antecedent.
2) Just between you and I, case is important.
3) A preposition is a poor word to end a sentence with.
4) Verbs has to agree with their subjects.
5) Don't use no double negatives.
6) A writer musn't shift your point of view.
7) When dangling, don't use participles.
8) Join clauses good, like a conjunction should.
9) Don't write a run-on sentence because it is diffic when you got to punctuate it so it makes sense when th reader reads what you wrote.
10) About sentence fragments.

Although not covered by the above rules, I would suggest that you watch your similes and metaphors. We have all seen mixed metaphors and noted how comprehension gets mixed along with the metaphor. A rarity along this line is a type that I call the "self-cancelling metaphor." The favorite in my collection was ingeniously concocted by the eminent microbiologist, L. Joe Berry. After one of his suggestions had been quickly negated by the ASM Council Policy Committee, Joe said: "Boy, I got shot down in flames before I ever got off the ground."

Self-cancellation can also apply to words. I recently heard someone described as being a "well-seasoned novice."

Which reminds me of the story concerning the graduate student recently arrived in this country from one of the more remote countries of the world. He had a massive English vocabulary, developed by many years of assiduous study. Unfortunately, he had had few opportunities to speak the language. Soon after his arrival in this country, the dean of the school invited a number of the students and faculty to an afternoon tea. Some of the faculty wives soon engaged the new foreign student in conversation. One of the first questions asked was: "Are you married?" The student said "Oh, yes, I am most entrancingly married to one of the most exquisite belles of my country, who will soon be arriving here in the United States, ending our temporary bifurcation." The faculty wives exchanged questioning glances—then came the next question: "Do you have children?" The student answered "no." After some thought, the student decided this answer needed some amplification, so he said: "You see, my wife is inconceivable." At this, his questioners could not hide their smiles, so the student, realizing he had committed a faux pas, decided to try again. He said, "Perhaps I should have said that my wife is impregnable." When this comment was greeted with open laughter, the student decided to try one more time. "I guess I should have said: My wife is unbearable."

Concluding Remarks

One final note. After you have written your paper, you will be wise to do two things.

First, read it yourself. You would be surprised how many manuscripts are submitted to journals without being proofread after final typing—manuscripts so full of typing errors that sometimes even the author's name is misspelled.

Recently, a manuscript was submitted by an author who not only was too busy to proofread the final typing of the manuscript, but also the covering letter. His letter read, "I hope you will find this manuscript *exceptable*." We did.

Second, it would be very wise to ask one or more of your colleagues to read your manuscript before you submit it to a journal. It may well be that the meaning of one or more parts of your paper is completely unclear to your colleague. Of course, this may be because he is dense, but it is just possible that this portion of your manuscript is not as clear as it might be.

Well, I guess it's time I stopped preaching. Like most editors, I sometimes get the feeling that nobody is listening.

Editors and managing editors have impossible jobs. What makes our work impossible is the attitude of authors. This attitude was well expressed by Earl H. Wood, of the Mayo Clinic, in his contribution to a panel on the subject "What the Author Expects from the Editor." Dr. Wood said: "I expect the editor to accept all my papers, accept them as they are submitted, and publish them promptly. I also expect him to scrutinize all other papers with the utmost care, especially those of my competitors."

After years of observation, I have decided that there are three types of editors: those who make things happen, those who stand by and watch what happens, and those who are always saying "what happened?"

I don't know how many of you read the comic strip *Peanuts*. My favorite shows Snoopy reading the reply from a publisher, after submitting one of his stories: "Dear Contributor, Thank you for submitting your story to our magazine. To save time, we are enclosing two rejection slips—one for this story and one for the next story you send us."

Somebody once said: "Editors are, in my opinion, a low form of life—inferior to the viruses and only slightly above academic deans."

Someone else said: "If you ever see an editor who pleases everybody, he will neither be sitting nor standing—there will be a lot of flowers around him."

At least I have learned that it sometimes is better to keep personal opinions *outside* of the editorial process.

For example, we once received an unusually good manuscript from a contributor whose previous papers were, shall we say, less than distinguished.

We rushed to pen and ink and wrote: "Dr. Smith, we are happy to accept your superbly written paper for publication in the *Journal*." And then we couldn't help adding: "Tell us, who wrote it for you?"

Dr. Smith answered: "I am so happy that you found my paper acceptable, but tell me, who read it to you?"

Now to summarize all that I have said: First, we are usually defined as "workers." In a zillion published papers, we see such expressions as "These workers reported that." Second, I have defined scientific writing as basically a matter of *organization*.

Thus, I leave you with the immortal words of Karl Marx: Workers of the World, Organize.