HOW TO WRITE A GOOD PAPER
(and thesis)

IVS “Crucial Skills for Scientists” Series

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The Problem:

• We spend ~20% of our time preparing “research reports” -- without training

• In contrast, we are trained to program computers, use oscilloscopes, SEM’s etc.
Lecture Objective

• Give participants “recipe” for preparing good research papers:
  – in terms of style and organization (content is up to you!)
  – acceptable to IEEE transactions, AIP and IOP journals, etc.
  – easy to read

• Not a substitute for full semester writing course
Lesson Plan

• Introduction: communications channel
• Before Writing
• English Composition Tips
• Organization of the Research Paper
  – Introduction
  – Method
  – Results
  – Discussion
  – Conclusions
  – (Abstract, Title)
• Summary and Conclusions
Journal Paper -- a communications channel

- Objective of scientific paper - convey information, as efficiently as possible.
- One writer - many readers -- burden on writer to communicate efficiently.
- Analog to broadcast channel -- Tx and Rx must be on same wavelength, use same protocol, expensive Tx, cheap Rx.
- Protocol for paper fixed by convention
Not a Murder Mystery!

- No virtue in keeping reader in suspense
- Reader wants info., not your personal history in arriving at results
  - Time sequence relevant, only to the extent that it affects result
- Organization, sequence of presentation optimized to convey information (not to make a good story!)
Before you begin to write – Define the “Research Question”

• Good research papers revolve around a “research question”
  – Example: “How does bias voltage affect the adhesion and interface structure of Ti-Al-N coatings applied to stainless steel substrates?

• In other fields (biology, medicine), the research question is stated formally.

• In our field, the Research Question should be:
  – Implicit in Phase 4 of Introduction (to be described)
  – Answered in the Conclusions
Ethical Issues

• Scientific Integrity

• Plagiarism – passing off someone else’s work as your own
  – Everything (ideas, data, pictures, etc.) in report must be yours, unless a reference is cited
    • No “cut and paste” from the web

• No “double publication”
English Composition Suggestions

• Hierarchal Structure ("top-down organization"):  
  – Chapter, Section  
    • Sub-section, etc.  
      – Paragraph  
        » Sentence

• Before writing text, write a detailed outline – down to the level of defining the topic of each paragraph  
  – Major problem – misplaced statements (method in results, results in discussion, etc.)
English Composition, cont’d

• “Bottom-up” organization:

• The sentence:
  – Expresses a complete thought
  – Most sentences should use the ‘natural’
    English word order: subject, verb, predicate
  “This relation is valid when x>r”
  “The chamber was evacuated with a diffusion pump”
English Composition –
The sentence, cont’d

– Simplify sentences by using strong natural verbs, rather than derived noun plus weak generalized verb:

**Not:** Measurements were made of the coating hardness using a nano-indenter.

Instead write: The coating hardness was measured using a nano-indenter.
The sentence, cont’d

– Avoid beginning the sentence with long prepositional phrases

*Using a CSEM model 3400 nano-indenter equipped with a flashlight and a microcomputer, the hardness of the coating was measured.*

Instead:

*The hardness of the coating was measured using a CSEM model 3400 nano-indenter equipped with a flashlight and a microcomputer*
The Paragraph
- Develops a topic
- At least 2 sentences, more preferred
- 1st sentence defines the topic of the paragraph
- Subsequent sentences develop idea in logical order
- Final sentence presents conclusion, or main point
In the final stage, the net deposition rate on the anode is zero. Cathodic material is either deflected by the high pressure A-plasma before it reaches the anode, or is re-evaporated after a very short dwell time. MP’s reaching the anode will likewise be evaporated. A given location on the substrate may be exposed primarily to C-plasma or A-plasma, according to the geometry of the electrodes and shields and the plasma flow dynamics, as illustrated schematically in Fig. 3.
Word Processor Instructions

• **Frequent back-ups**
• Use defined “styles” for headings, etc.
• Indent, extra space before new paragraph
  – Build into style
• Use automatic endnote numbering
• Do NOT insert extra blank spaces or blank lines
  – It defeats automatic features of word processors
  – Use TAB to control horizontal spacing
  – Use “insert line” and “page break” if needed
## Organization of the Paper

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>Summarizes work</td>
</tr>
<tr>
<td>Introduction</td>
<td>What are we talking about?</td>
</tr>
<tr>
<td>Methodology</td>
<td>What did we do?</td>
</tr>
<tr>
<td>Results</td>
<td>What did we get?</td>
</tr>
<tr>
<td>Discussion</td>
<td>So What?</td>
</tr>
<tr>
<td>Conclusions</td>
<td>~3 key points you want reader to remember</td>
</tr>
</tbody>
</table>
Trapezoidal Organization

- Introduction
- Methodology
- Results
- Discussion

Broad background
Narrow focus
Broad implications
Introduction

I. General Background

II. Literature Review

III. Gap

IV. Objective
Introduction

• Introduction and Discussion hardest for the novice to write well!
  – (Exp. Details, Results much more straightforward)

• Objective of the Introduction: give reader sufficient background information so that he/she can understand and appreciate your work!
Introduction

• 4 Required parts:
  – I. General background
  – II. Literature Review
  – III. Gap
  – IV. Statement of Purpose

• 2 optional parts
  – V. Value statements
  – VI. Preview
Intro: I. General Background

• Purpose:
  – Place paper in broad context
  – Bring reader up to speed

• Style
  – Should be understandable by every reader
  – Defines topic
  – Short (1 par., ~3-5 sentences)
  – Usually very general, non-controversial sentences
Intro: II. Literature Review

• Purpose
  – Places paper in specific context.
  – Sets the stage for stating what was not done previously (in III) by showing what was done,

• Organization – order citations by:
  – Approach (end with that closest to yours).
  – Relevance (end with most relevant)
  – Chronologically (end with latest)
Lit. Review, cont’d

• **DO NOT USE REFERENCE NUMBERS AS WORDS!!!**
  – **NO:** Examples of crack propagation in composite materials are given in [1-4]
  – Instead: **Crack propagation has been previously investigated [1-4].**
  – If you have to ‘say’ the number for the sentence to make sense, rewrite!
  – Better to cite work by authors name (followed by ref. number). **Reader can relate to names** – numbers (only) force him to stop reading and search for references at end of paper.
Lit. Review, cont’d

• Your own previous work?
  – Treat your own previous work fairly
  – Referees and readers very suspicious if work of author or author’s group cited out of proportion, or work of others ignored.
Intro. – III. Gap Sentence

• Summarizes state of knowledge by indicating:
  – What was not done, or
  – Errors in previous work (be careful and tactful!), or
  – Disagreements, controversy between various sources.
Gap Sentence

• **Most important sentence for getting paper accepted!**
  – *(most?)* common cause for paper rejection – nothing new
  – Gap sentence, by indicating what wasn’t done previously, shows that your work is new!
  – A good gap sentence forces reviewer to work hard to reject paper for lack of novelty
Intro. – III. Gap Sentence (cont’d)

• Usually 1 sentence long
• **Always negative**
• Must relate to previous papers by you and your group in same manner as other papers
• Sentence should be *explicit, precise*, and *focused*:
• Example: “The dependence of the interface structure between Ti substrates and Al films on the substrate bias voltage has **not** yet been determined.”
Intro. – III. Gap Sentence (cont’d)

• Don’t be wishy-washy
  – “Few research have investigated…..”
    • Begs the question – “what about the few?”
    • The “few” should be the focus of the lit. rev., and the gap should be relative to them
  – “To the best of our knowledge, no one has…..”
    • It’s the authors’ job to know the literature!
Intro. IV-Statement of Purpose

- Immediately follows gap sentence
- States objective of the research/paper, which is, basically, to fill the previously stated gap
- Should be concise, precise, explicit and focused
  - The “research question” should be implicitly clear!
- Example: “The objective of this research was to determine the dependence of Al/Ti interfaces as a function of substrate voltage during vacuum arc deposition”
Intro. IV-Statement of Purpose

• Style notes:
  – The objective of research is \textit{not} to do research (or study, investigate, etc.)
    • Instead, use more decisive terms – measure, determine, construct, calculate, etc.
  – “research” centered SOP – use past tense
    • The objective of the (research, project, investigation, etc.) \textit{was} …. (preferred)
  – “paper” centered SOP – use present tense
    • The objective of this (paper, report, article, etc) \textit{is}…. 
Intro. – Optional Parts

• V. Statements of Value
  – Indicate importance or significance of work
  – Short (1-2 sentences)
  – Modest tone

• VI. Preview
  – Useful for long papers
  – Give principle result
  – Indicate organization
Methodology

• Sometimes called:
  – Experimental Apparatus and Procedure
  – Experimental Details
  – Methods and Materials (bio, med)

• Do **not** call it ‘Experimental’ (an adjective
  -- a title must include a noun)

• Answers the question “what did I do?”
Methodology

- Amount of detail: **absolutely must include sufficient detail so that every result presented can be duplicated elsewhere**
  - If you have secrets necessary to get the results, don’t publish!
- Nice to report details which would help your readers
- Eliminate extraneous detail
Methodology

- Start with Apparatus
- Standard or well-known apparatus – mention, define, give ref., as appropriate
- Non-standard, not well-known, - describe
  1. Define purpose
  2. Give brief overall description (use a diagram)
  3. Describe parts
     Some logical order (signal or material flow, left-right, top-bottom, etc.)
  4. Describe inter-relation of parts, operation.
Apparatus Diagrams

• Schematic – show only parts necessary to understand operation
  – All parts mentioned in text should be labeled in diagram
  – All unusual parts in diagram should be described in text

• No workshop drawings
  – too detailed
  – lines too thin

• No photographs
  – Easier to understand schematic drawing
“Heads-up Display”
Eye-tiring figure:
Eye needs to jump back and forth from fig. to caption or text
Methodology – Style and Grammar

• Usually past tense
  – present tense for general truths, generic description of standard equipment

• Voice
  – Human agent – passive (avoid I, we, etc.)
    • The voltage was adjusted *by the experimenter* to 15.4 V.
  – Instrumental agent – active or passive
    • The generator produced a series of 50 V, 50 ns pulses.
    • A series of 50 V, 50 ns pulses was produced by the generator
Exp. Details – Style and Grammar

• Articles
  – First mention of a part – use “a/an”
  – Subsequent mention – use “the”

• Word order
  – Start with old information (i.e. part already described), then give new information

Example: The ions were produced with a Kaufman source. The source was positioned 25 cm from an acceleration grid.
Exp. Details – Exp. Procedure

• Sequence of events followed to conduct experiment
  – Give sufficient detail to duplicate results
  – Don’t give unnecessary detail

• Specify all experimental conditions/parameters required to duplicate results (e.g. pressure, temperature, voltages, fields, flows, etc.)
  – Give specific common, fixed values
  – Indicate range of variable parameters
  – Table summarizing exp. parameters is useful
## Table summarizing parameters and experimental variables

<table>
<thead>
<tr>
<th>Fixed Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode diameter</td>
<td>50 mm</td>
</tr>
<tr>
<td>Anode i.d.</td>
<td>160 mm</td>
</tr>
<tr>
<td>Axial Magnetic Field</td>
<td>100 mT</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode Materials</td>
<td></td>
<td>Zr, Hf, Ti</td>
</tr>
<tr>
<td>Cathode Current</td>
<td>I</td>
<td>50-150 A</td>
</tr>
<tr>
<td>Deposition Time</td>
<td>T_d</td>
<td>60-180 s</td>
</tr>
</tbody>
</table>
Theoretical Papers – Model Assumptions, Derivation of Equations

• Also answers “what did I do?”
• State all assumptions first, then develop equations
• Give sufficient detail for duplication elsewhere
  – Shouldn’t need to work weeks to progress from one equation to the next!
Theoretical Papers: Nomenclature

• Define each symbol
  – Either 1st time used, or
  – In Nomenclature Table

• Recommendation – Prepare Nomenclature Table for internal use. 4 Columns:
  – Symbol
  – Definition
  – Pages upon which it appears
  – Page containing definition
Results

• Answers the basic question, “What did I get” or “What did I observe”
• Typically, most results given in tables and figures. Text revolves around them.
Results, cont’d

• Three Information Elements – types of sentences

*Location* (L) sentences indicates which figures or tables contain a particular result.

*Presentation* (P) sentences present the most important findings.

*Comments* (C) are sentences which comment on the results.

• Sometimes L&P are combined in a single sentence.

• Never combine C with anything else.
Results, cont’d

<table>
<thead>
<tr>
<th>type</th>
<th>example</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>The correlation parameter as a function of distance from the jet outlet is shown in Fig. 3.</td>
</tr>
<tr>
<td>P</td>
<td>It may be seen that the correlation decreased steeply with distance, and became negligible after 5 cm.</td>
</tr>
<tr>
<td>C</td>
<td>This results differs significantly from those observed with conventional jets.</td>
</tr>
<tr>
<td>L&amp;P</td>
<td>The wavelet intensity had a Gaussian temporal profile, whose width decreased with the distance between the sources, as may be seen in Fig. 4.</td>
</tr>
<tr>
<td>C</td>
<td>This is similar to the results from ring sources.</td>
</tr>
<tr>
<td>L&amp;P</td>
<td>The wavelet intensity had a Gaussian temporal profile, whose width decreased with the distance between the sources (Fig. 4).</td>
</tr>
<tr>
<td>L</td>
<td>Table 5 summarizes the composition and wear properties of coatings deposited under various conditions.</td>
</tr>
</tbody>
</table>
Results - Style and Grammar

• Location sentences
  – In present tense
  – Both active & passive OK

• Presentation sentences
  – Summarize most important results of tables and figures – “Blind man’s rule”
    • Presents what can really be seen in figure
  – Usually use past tense
  – Be precise, and as quantitative as necessary/possible
Increasing Information in Presentation Sentences

1. It may be seen that $Y$ depended on $X$.
2. It may be seen that $Y$ increased with $X$.
3. It may be seen that $Y$ increased linearly with $X$.
4. It may be seen that $Y \approx 22.3 \times X + 32$. 
• Comment sentences:
  – For interpretations, explanation, comparisons,
  – Only comments intimately related to specific finding.
    • Put more general comments in Discussion!
Results – all the conditions!

• Be sure that all the conditions, parameters, etc., required to obtain a particular result (e.g. in a specific figure) are given!

• If the conditions are not completely specified in “Experimental Details” (e.g. if there were variable parameters), then they must be given either in Location sentence, caption or figure.

• Always give conditions first, then the result.
  – 1\textsuperscript{st} - what you did,
  – 2\textsuperscript{nd} - what you got
Results – figures and tables

- Choose most appropriate format to make your point
  - Table where absolute value is most important
  - Graph where trend or comparison is most important
    - Trend – line graph
    - Comparison – bar graph
  - Choose x axis so it (and not a parameter) represents the most important variable
Results – figures and tables

• Heads-up display – all required info on the graph (if possible), rather than in caption or text
• But - don’t crowd
• Illiterate man’s rule
  – Figures should be understandable to an illiterate!
• Don’t be lazy – author should work, not reader
• Always specify units .
  – Do not use \( V, \times 1000 \)
Discussion

• Answers the question “So what?”

• **Typical Elements in the Discussion**
  – **Specific reference to the present study:**
    • 1. Reference to the main purpose or hypothesis
    • 2. Review of the most important findings
    • 3. Limitations and justifications:
      * demonstration of self-consistency (e.g., with model assumptions)
      * demonstration of statistical validity
      * technique limitations, and their implications (e.g., bandwidth of instrument→high frequency components, if existent, cannot be observed)
Discussion, cont’d

4. Comparisons
   * between different elements of the present studies
   * with previous works (between various theories, between various experiments, between experiment and theory, or theory and experiment)
Discussion, cont’d

– General statements
  • 5. Explanations, implications and generalizations
  • 6. Recommendations
    * for future research
    * practical applications

• In general, discussion starts with specific statements re. present study, and diverges towards more general statements.
Discussion, cont’d

• Major problem – correctly conveying degree of certainty (of explanation, implication, etc.)
  – Faulty or absent analysis by author
  – Wrong choice of words
  – It’s o.k. to offer speculative explanation, if
    • clear to the reader that it’s a speculation
    • short
## Certainty Scale

<table>
<thead>
<tr>
<th>Category</th>
<th>Use</th>
<th>Key Words</th>
</tr>
</thead>
<tbody>
<tr>
<td>speculation</td>
<td>idea or ideas that come to mind</td>
<td>may, possible, conceivably</td>
</tr>
<tr>
<td>likely</td>
<td>some evidence supports this idea</td>
<td>suggests, indicates</td>
</tr>
<tr>
<td>very likely</td>
<td>substantial evidence supports this idea</td>
<td>is consistent, strongly suggest</td>
</tr>
<tr>
<td>most likely</td>
<td>There is more evidence and/or theoretical support for this idea than any other existing idea</td>
<td>most likely</td>
</tr>
<tr>
<td>proven</td>
<td>All possible explanations are on the table, and a decisive test indicates that this idea and only this idea explains the observation</td>
<td>proven, proves, proof, shown, demonstrated</td>
</tr>
</tbody>
</table>
Discussion

• Don’t introduce “new” results in the Discussion !!!
  – Don’t present “new” facts in the discussion !!!
  – The discussion should discuss results presented earlier in the paper, or in the literature (with a specific reference).
Conclusions

- May be the concluding paragraph of the discussion
- or separate section, entitled “Conclusions”, or “Conclusions and Recommendations”
- Should be very short (1-2 paragraphs)
- Don’t repeat objectives or methodology
- Don’t use indicative sentences
  (e.g. *The microhardness and critical load were measured as functions of the substrate temperature.*)
Conclusions

- No “new” information – this section should summarize results and ideas which are presented and developed in detail in previous sections (i.e. results and discussion).

- Summarize the most important results, and their implications. (again this is a summary, the implications should have been developed and discussed in Discussion).

- Think in terms of 3 things you want the reader to remember
Conclusions

• **Answer the “research question”**.

• Self-contained – avoid references (either internal *(e.g. see Fig. 3)* or external)

• **Recommendations for further work.**
  – Must be firmly based on the present work.
Abstract

- Write draft before writing body of paper
- Re-write when done
- Summarizes in 1-2 sentences each:
  1) background,
  2) objective
  3) methodology
  4) most important results
  5) conclusions
Abstract, cont’d

• Many read only abstract (abstract journals), ➥ make it informative, not merely indicative

□ ➥ Indicative example: The voltage as a function of temperature was measured.

□ ➥ Informative example: It was found that the voltage decreased as a function of the temperature, reaching a saturation value of 30 mV.
Abstract, cont’d

• Abstract should stand alone – no references.
• Abbreviations:
  – use only if a term is used repeatedly within the abstract,
  – and its use will save considerable space.
  – Define each abbreviation the first time it is used.
Title

- Compose title and detailed outline at the beginning of the writing process
- Re-evaluate and correct title after the paper is written
- Short (<2 lines, 1 is better)
- Accurately express the subject of the new results presented
- No abbreviations!!!
Summary – 10 Commandments for writing a good paper

1. Have a well defined ‘research question’
   - Implicit in ‘statement of purpose’ in intro.
   - Answered in conclusions

2. Organize paper in standard manner
   (Introduction, Experimental Apparatus and Method, Results, Discussion, Conclusions)
   - Prepare an outline before writing text
   - Put each statement into the right place
Summary – 10 Commandments

3. Explicit gap sentence in introduction
4. Give all the details required for duplicating results
5. Results: Location, Presentation, Comment
6. Good graphics – easy to read and understand
7. Be modest in explanations, implications
8. Polish each sentence
9. Informative abstract
10. Work hard to make readers’ job easy
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