USING A GENERIC CHECKLIST FOR TEACHING AND GRADING THE FORMAT, COMPOSITION, AND PRODUCTION QUALITIES IN LABORATORY REPORT WRITING

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Abstract

An itemized checklist on the format, composition, and production qualities expected in experimental engineering reports is presented and described. The checklist can be used as an instructional tool, a working reference, and a grading instrument. Methods to implement its use are also described, and a quantitative evaluation of its effectiveness in teaching is presented.

Introduction

As most laboratory instructors will attest from direct experience, many or even most contemporary engineering undergraduates appear to have had limited instruction in the standard format, composition, and production qualities expected in laboratory reports. Indeed, since undergraduates encounter little primary practical or research literature, they will have had limited experience in even reading reports with the structure, quality, and clarity that should be expected from engineering professionals. For examples, students are largely unaware of the importance of a neat and orderly page design with uniform margins, descriptive headings, and distinctive paragraphs. Equally or possibly evenly more important are well designed and executed exhibits, particularly equations, tables, and graphs. The laboratory instructor faces a challenging task in presenting both the general concepts of report writing and the details and techniques that are needed to allow the concepts to be implemented. Furthermore, the instructor is strongly challenged to effectively motivate the students to apply these concepts in detail. Indeed, for many students the engineering laboratory course appears to be their initial experience with a task in which detailed quality control of any type is emphasized.

This experience of this laboratory instructor has prompted the development of a generic checklist of the concepts and details relevant to efficient and effective format and production qualities report writing. The checklist is first an instructional tool used to inform the student of the expected practice in academic experimental reports. It is next a guideline and reference for the student during report preparation. It is then a checklist for the student to use when reviewing prepared reports. Finally it is an efficient, effective, and fair tool for grading the completed reports. The generic checklist presented in this paper is the product of several years of experience with a large enrollment laboratory course. The checklist has proved useful as an instructional tool and as a student resource. It has been especially useful as a grading instrument for promoting efficiency and consistency among lab instructors and teaching assistants. The effectiveness of this instrument will be demonstrated by comparing the relevant format, composition, and production quality scores of several terms of students first as entering and then after only a few weeks through the course. Significant improvement without major investment in instructional time can be demonstrated.

Background

As part of a continuing effort to teach and encourage improved report writing, this author and a colleague prepared a writing style and standards manual[1] for our undergraduate students that was finished and published locally in 1999. This manual actually represented the culmination of several years of piecemeal efforts that were complicated by the need to distill the essence of several published national standards and the expectations of our local colleagues into a consensus practical standard. When this handbook was finally printed, the finished product extended to 202 pages. This length is too great to retain the attention of most engineering undergraduates. Continued editing should reduce its length somewhat; however, even with successful editing any such manual will remain rather lengthy for at least three reasons. First, it needs to be reasonably comprehensive even if not encyclopedic. Second, it must contain examples of the several types of reports[6] that we expect students to produce over a professional career or even during a college curriculum. Finally, guidelines on the desired format and production qualities are almost useless without some specific instructions on how to implement these standards using contemporary word processing and numerical spreadsheet software. Consequently, the manual must also contain instructions on the document, graphics, and data processing skills needed for success in a typical undergraduate sequence of experimental engineering courses.

The author uses this manual and the generic checklist in a senior level engineering systems laboratory course. This course is the second in a series of three required mechanical engineering lab courses. The first course is an instrumentation and measurements course that concentrates on lab procedures and data processing. The third course is an experimental engineering project course in which students plan and execute an experimental project that spans an entire semester. The engineering systems course is broken into two sequences. One is a sequence of mechanical systems experiments. In this sequence oral and visual presentation is emphasized. The other is a sequence of thermal energy and fluid mechanics experiments. This sequence emphasizes written reporting, and students are required to prepare several group reports and two individual reports during the sequence. It is this sequence in which the subject checklist is used.

For classroom presentation, the bare essentials of writing style and format and production quality standards have been condensed into a set of 20 slides that can be discussed in about one lecture period. A copy of these slides is available to interested instructors on line[4]. This slide presentation has been developed from a condensed summary text that is included in the experimental laboratory manual. This condensed section is a ready reference that covers most of the style and standards topics in minimal detail in about 50 pages. At this point, the evolution and condensation of our writing guides had been from a comprehensive, but not encyclopedic, text of 202 pages, to a summary ready reference section of 50 pages, and finally to an oral visual overview in 20 slides.

At this time it was recognized that the students understand and employ writing and production techniques better the more the focus of the instruction was narrowed and the more the objective of the instruction was made more concise and explicit. A particular point of focus has been one key exhibit in the slide presentation, a one page table of report writing essentials. This one-page table contains only 34 entries, but experience has shown that attention to these items would ensure a minimally successful report. Recall that all the basic concepts of thermodynamics can be presented as three or four general laws and a few supporting phenomenological statements. By analogy, it could be expected that the relatively straightforward task of composing an engineering report should not require many more general principles and essential details than would fit in a one or two page table. Originally, the one-page table was only part of a classroom presentation. Then it was also used as an auxiliary grading sheet. Later as it became clear that the bare essentials of technical report were actually represented in the table, it was modified and expanded so that it could be used not only as a grading instrument but also as an instructional tool and a working reference.

The original one-page table was a bit too cryptic to be used alone as it was merely intended to be a guide to the balance of the ready reference text. The slide itself is mostly a table of topics with no details. Consequently, most of the entries were expanded to give a minimal working definition of the original bare topic along with some crucial details and occasional examples. The resulting two-page checklist, which remains a work in progress, is reproduced in the appendix. A printable version is also available on the author's web page[5].

Features

As seen in the appendix, the current version of the checklist has six principal sections with several topics in each section. The features of each section are briefly discussed below.

The first section is concerned with overall document design, including page design, headings, and font selection. The importance of uniform margins is emphasized. No other fault spoils the appearance of a report as a finished product more than wide margins, which are usually caused by poorly placed exhibits. Non uniform margins are also always interpreted as markers of poor proofreading and scanty attention to detail. Worse, readers will likely be interpret uneven margins as markers for dubious content generally. Students are also cautioned to follow the ISO[3] standard by using Italic for math symbols and math symbols only while notes, labels, names, and units should be in the vertical text style. This international standard is very helpful to the reader, as Italic symbols stand out distinctly in the test. Students probably have not been taught and apparently have not learned by example this very useful convention, so it is emphasized here. The importance of headings in organizing a technical report is also stressed. Attention to this section ensures a report with at least minimally acceptable physical appearance.

The next section is concerned with general composition and content. Students have been reassured that the general outline of an experimental report is almost routine, but they are cautioned and encouraged to outline every specific report in longhand before plunging ahead with the word processor. Here the importance of sentence and paragraph design are also stressed. The two major design rules for both structures are analogous. First, avoid run-on sentences with proliferating clauses or run-on paragraphs with multiple topics. Second, avoid sentence fragments that do not express a complete thought and avoid paragraph fragments that do not develop one particular topic. Scrupulous and thoughtful attention to this section ensures a report of acceptable organization and content.

The next section is a set of specific composition rules on the topics of capitalization, common typographical errors, basic grammar, and spelling. A particular cautionary note on misuse of parentheses is included. This caution is emphasized because students are tempted to use parentheses promiscuously, and parentheses almost always disrupt the natural order of a sentence. Careful attention to this section ensures a report with minimal detailed faults.

The next section is concerned with citing and listing references. References are crucial to scholarship and credibility. Students are directed to use a standard method to identify every reference cited in the text. The author-date method is simple and easy to manage, and it seems to be predominant in technical work. Therefore, it is prescribed for our students. The importance of avoiding informal remarks instead of formal citations is emphasized. Indeed, undergraduates have so little experience reading research literature that they will use literally illiterate remarks such as “our thermo text”. Since undergraduate students rarely encounter primary research literature, the opportunity is taken to encourage students to eschew textbooks and other secondary references in favor of primary literature. Students are reminded to list every cited item in the reference section using a standard bibliographical format. The most important examples of reference listings are given in the checklist, and a complete presentation is available in the style and standards manual. Even cursory attention to this section should ensure a report with adequate citations and reference listings.

The next section is concerned with some specific issues in technical writing. The most important topics here are on significant digits and units. Students are reminded to report only significant digits in text and tables. Unfortunately, instruction on the importance of significant digits and on how to identify them seems to have become unfashionable or at best inconsistent. The general rules are presented here, but some significant additional classroom instruction is always necessary, even at the senior level. Students are reminded to accompany dimensional data with the units. For consistency, SI units are required to be primary. Careful attention to this section ensures a report correct in significant digits, units, and other technical details.

The final section is concerned with summary guidance on effective and professional exhibits. The overall design and the finer details in exhibits are both important. General guidance and guidance on equations, graphs and figures, lists, tables, and attached spreadsheets are given. Students are cautioned that a numerical spreadsheet is probably too informal to be included in a formal report. However, spreadsheets are almost universal for processing data, and they are frequently included in internal reports. The importance of structuring spreadsheets for clarity and reliability is emphasized. Careful attention to this section should ensure a report with adequate exhibits of all types.

Implementation

The checklist is presented and used in several ways to implement its functions as an instructional tool, a working reference, and a grading instrument.

As an instructional tool, the checklist is introduced during an introductory lecture on report writing and course policies. The accompanying oral presentation makes note of the important entries in the checklist as described in the previous section. Students are given a copy of the checklist in their manual, and a copy is posted on the course web page.

As a working guideline students are urged to review the checklist before preparing every report and to use it as a reference when reviewing the completed report. Occasional comments and anecdotal evidence indicate that some students actually follow these recommendations.

Using the checklist as a grading instrument is probably its greatest benefit to the instructor. It saves time and appears to increase the effectiveness of grading. In this one modest aspect, this document mimics the well-know work of Strunk and White[9, 10] that is probably the most popular and important writing textbook ever published in America. A recent review[2] stated that White reported that Strunk[8] constructed his text from the start as a set of numbered rules to index during grading as a laborsaving device. Quite independently and by chance, this author follows the same practice. The following passage is a typical but contrived example of student writing that includes errors identified in the checklist:

A/2

> The dynamic pressure was measured with a Dwyer Durablock Series 100, which has an uncertainty, estimated on the basis of measurement resolution, of 1.27 mm (.05 inch).

B/2

Each error in this passage is marked with an index letter and penalty. The index letter is repeated on an attached copy of the grading checklist; therefore, the student is thoroughly informed of the specific cause of the penalty and the recommended acceptable practice as follows:

A B

<u>Identifying Equipment.</u> Use the "generic (commercial)" style to avoid "technician speech".

<u>Significant Digits (SD).</u> Never display insignificant digits in text or tables. Measured data has same least significant digit (LSD) as the LSD in its uncertainty (*i.e.*, 314 ± 2 or 27.18 ± .12). For routine calculated data use the simple **approximate** rules. For example, the result of addition or subtraction is assumed to have the same LSD as the larger LSD in the two original numbers (*i.e.*, 25 + 273.15 = 298). Further, the product of multiplication is assumed to have the same number of SDs as the factor with the lesser number of SDs (*i.e.*, 2,718 × 3.14 = 8530). Similarly, the quotient or result of division has the same number of SDs as the lesser number of the SDs of the divisor or dividend (*i.e.*, 27,180 ÷ 31.4 = 866). For **very complicated or very important** calculated data use error propagation to calculate the uncertainty.

Most students seem to accept this procedure for grading as being fair. This acceptance is probably because the students have demonstrably been informed in writing of all the potential errors and penalties well in advance. Note that a few generalized entries, such as the mandate that a graph "Emphasize accuracy and legibility", are included to give some flexibility in grading since every detailed error cannot be anticipated. In rare events a unique or unusual error is encountered that is outside the scope of the checklist. It can usually be assumed that such an error is beyond the scope of the instruction as well. The usual practice then is merely to insert a written comment and not assign a penalty unless the error is particularly egregious. The checklist ensures that the grading is explicit and coordinated with the instruction; consequently, fewer comments like my all time favorite "your not an english prof, dont count off for grammar" are received.

More recently, an extra incentive has been introduced to encourage the students to compose and proofread their reports more carefully. The incentive is to give separate format and production quality grades for both of the individual reports produced by every student each term. If students achieve an average grade of 92 or merely a second grade of 94, they are exempted from an assignment to correct and resubmit the second individual report. The students are warned that the reworked report will be especially harshly graded and that additional points will be deducted from the original grade for any graded errors not corrected and residual errors not detected and corrected.

Results

Qualitatively, the improvement in student technical writing during the engineering systems laboratory course seems to be impressive, and the improvement seems to persist into the following experimental engineering project course. All of the improvement cannot be attributed to using the guideline checklist, but it surely contributes. In addition to the instructor's qualitative evaluation, a quantitative assessment can be based on the data in Table 1.

Table 1. Statistical Data and Analysis

		P-S		V-P				
term	number	average	SSD	average	SSD	ESE	t_{test}	*P**
summer 2000	47	93.3	2.96	96.2	2.66	0.580	4.910	0.000
fall 2000 A	58	92.9	3.76	94.6	4.07	0.728	2.337	0.012
fall 2000 B	60	92.9	4.04	95.0	3.87	0.722	2.908	0.003
spring 2001 A	51	93.0	4.25	94.1	4.34	0.851	1.293	0.101
spring 2001 B	59	92.4	4.03	93.2	5.29	0.866	0.924	0.180
summer 2001	45	93.0	4.14	95.5	3.64	0.822	3.054	0.002
fall 2001 A	54	89.0	4.88	94.3	3.80	0.842	6.297	0.000
fall 2001 B	43	88.5	5.33	95.4	3.47	0.970	7.073	0.000
total	363							

*The probability, $P = P(t > t_{test})$, that a random variable with the t-distribution centered on zero could have a value greater than the test statistic.

The quantitative evaluation of student improvement is possible since separate format and production quality grades are assigned using the generic checklist for two individual reports. The first report (P-S) is on an experiment using the Pitot-static probe to investigate the flow behind an obstruction in a wind tunnel. The second individual report (V-P) is on an experiment to investigate the vapor pressure of Refrigerant 134a. For the passed two years the checklist has been used essentially as described in the implementation section above. The format and production quality grade data for these years are presented in the table. The first experiment has typically been conducted during the first or second week of the sequence, and the second has typically been three or four weeks later. Note that during a regular semester two groups of students, A and B, take the sequence in turn. The sequence lasts seven weeks out of a fifteen week semester. In a summer session there is only one group on a modified schedule.

The average and Sample Standard Deviation (SSD) of the scores for both individual reports for each group are given in Table 1 above. A quick glance shows that the scores improve from the first to the second individual report for every group, but is the improvement statistically significant? A t-distribution test is appropriate to evaluate whether the improvement is significant. Several statistics are needed to implement this test. First, the blended Estimated Standard Deviation (*ESD*) for each pair of scores is first calculated by the following formula for the combined standard deviation. This formula is recommended in standard statistical manuals such as that by Spiegel[7]. Since both samples have the same number of data, *N*,

$$ESD^2 = \frac{(N-1)SSD_1 + (N-1)SSD_2}{2N-2} \tag{1}$$

The statistic calculated in Equation (1) is the best estimate of the variance of the individual grades in the entire population represented by the data for both reports for one group of students. Note that each group included 43 to 60 students. Next, the two sets of data in each pair are assumed to be independent samples, then the Estimated Standard Error (*ESE*) for the difference in the means can be computed as follows,

$$ESE^2 = \frac{2\,ESD^2}{N} \tag{2}$$

The statistic computed in Equation (2) is the best estimate of the variance in the average grade on one report for a group of students. Note that since each group included from 43 to 60 students, the estimated variances for the averages are of course much smaller than the variances for the individual grades.

If using the checklist improved student performance appreciably, then the average grade on the second report for each group should be significantly higher than the average grade on the first report. To test this performance statistically, the tentative hypothesis that the individual scores for both reports come from identical populations is asserted. If it were true, then any differences between the averages would be merely due to chance. Note that this hypothesis is already seen to be highly unlikely since the average score for every group improved. To test this null hypothesis, compute the following test t-statistic,

$$t_{\text{test}} = \frac{\bar{x}_2 - \bar{x}_1}{ESE} \quad (3)$$

Where $\bar{x}_1$ = the average grade on the first report, and
$\bar{x}_2$ = the average grade on the second report

This test statistic is essentially the normalized difference between the average grades for a given group of students. If the two average grades were from identical populations, the normalized differences would be relatively small, and some would be negative and some would be positive. If many such cases were studied, the average normalized difference would be zero. In the current application, the normalized difference is always positive, and the statistical significance of this trend can be evaluated by calculating the possibility that such a large positive difference could be obtained from the random selection of a difference taken from a population centered on zero.

A large value for the test statistic is evidence against the null hypothesis that the grades are not changed by using the checklist. Indeed a large value, say around two or more, is evidence in favor of the implication that using the checklist improves student performance. To quantify the test, the probability that a random variable from a t-distribution centered on zero could be larger than the observed test statistic is evaluated, and that value is used as the criterion for significance. If the probability is small, conventionally < 5 %, then it is very unlikely that the observed increase could arise from chance, and the observed difference can be taken to be statistically significant. Since the test statistic is a normalized random variable that can be assumed to be governed by an approximate t-distribution, the required probability can be readily computed. Table 1 shows that the probability of having a chance increase as large as the observed increase is very small in six of the eight cases. The probability is almost vanishingly small in three of these cases and barely more than one percent in the worst case. In all six of these cases the improvement is statistically significant by the conventional criterion. In the two other cases the conventional limit is exceeded, but even in these cases the improvements was substantial. While the improvement cannot be attributed strictly to the use of the guideline and checklist, this instrument is a critical part of the instructional approach that has been shown to be effective.

Closure

The itemized checklist presented and described in this report is the product of several years of development and experience. The checklist has been found to be useful as an instructional tool, a working reference, and a grading instrument. A quantitative evaluation of its effectiveness shows that it has been significantly effective as a teaching tool.

References

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Biography

SHELDON M. JETER is Associate Professor of Mechanical Engineering at the George W. Woodruff School of Mechanical Engineering at Georgia Tech. He has degrees from Clemson University, the University of Florida, and Georgia Tech. He has been on the academic faculty at Georgia Tech since 1979. His research interests are thermodynamics, heat and mass transfer, and energy systems.

Appendix: Generic Guideline and Check List

OVERALL DESIGN RULES

Page Design. Allow uniform 2.5 cm (1 inch nominal) margins all around. Avoid wide margins caused by poorly placed exhibits. Relocate or resize exhibits or insert unobtrusive extra lines to avoid wide margins or dangling exhibits, headings, or lines. Use 12 point Times New Roman font with 1.5 line spacing with text full justified, as this is. Insert extra line after every paragraph or section. Use standard section and subsection headings, left justified, if required. Display proper letterhead on first page of letter report only. Center titles of exhibits. Emphasize orderly and professional page design.

Font. Fonts in text and exhibits must be legible and conventional in size and style. Use 12 point Times New Roman for all text in body of report. Use *Italic* for math symbols included in paragraph text and in equations, use vertical text style for accompanying units, notes, names, or identifying scripts. Use bold capitals for **SECTION HEADINGS**, bold only for **Sub-section Headings**, and underlining for Sub-subsections. Also use underlining for optional run-in Paragraph headings. Use *Italic* for all math symbols. *Italic* is required for foreign words including *i.e.*, *e.g.*, and *etc*..

Headings. **SECTION** and **Sub-section** headings must be flush left on a separate line. Run-in paragraph headings are underlined and then indented just like any first text of a paragraph. Never leave a heading dangling on the last line of a page.

Symbols. Use *Italic* for all math symbols in text and equations, but use text style for accompanying units, notes, and function names. Also use text for identifying scripts that are merely labels not symbols themselves as in "$P_{\text{abs}} = P_{\text{g}} + P_{\text{atm}}$". Avoid E-format in text; instead write "2.72×10^2" not 2.72E2. Avoid awkward makeshift typewriter symbols, such as * for multiplication or ^ for exponentiation, in text (*e.g.* avoid "a^2 = a*a"; use "$a^2 = a\ a$").

GUIDELINES ON GENERAL CONTENT AND COMPOSITION

Correct Content. Always outline the report in your notebook before plunging ahead on the keyboard. Use judgment to avoid presenting any unnecessarily detailed information in the introduction. Avoid citing the literature or even exhibits that are part of the report in the introduction. Address all required issues in the substantive sections under the appropriate section headings. Always address the uncertainty of measurements and the calibration status of critical instruments. In advanced or professional work include error analysis. Avoid introducing any new information in the closure.

Paragraph Style. Develop at least one but only one significant topic per paragraph. Avoid incomplete paragraph "fragments", and avoid multiple, unrelated topics in one "run-on" paragraph. Draft structured integrated paragraphs. Include a definitive topic sentence. Finish with a smooth transition sentence or a definitive summary sentence. In ME 4053 Thermal/Fluids, identify the topic sentence by circling the first word in the paragraph as has been done for this paragraph. Use a list to simplify or organize an especially complex paragraph that is burdened with technical details.

Paragraph Format. Always use the modified block format, indenting first line and skipping line after last line. Use paragraph headings occasionally for special emphasis.

Sentence Construction. Use an impersonal narrative in technical writing. Avoid the first person. Use the passive voice in an impersonal construction when necessary to avoid mentioning individual persons. Write "the data were collected" not "I collected the data". Use the active voice in an impersonal construction in most other cases to produce a simpler narrative. For example write "temperature increased the pressure" not "pressure was increased by the temperature".

Sentence Style. Emphasize simple sentences in natural order. Natural order is subject, then verb, and then object or predicate. Avoid sentence fragments. In particular, every declarative sentence must have a subject and a verb. Imperative sentences with a merely implied subject are almost never used in reports. Scrupulously avoid run-on sentences and avoid very long sentences even if correctly punctuated. Sentences should very rarely have more than two complete clauses. Occasionally use two coordinate clauses in a compound sentence or an independent clause and a dependent clause in a complex sentence. Clauses in compound or complex sentences should themselves be in natural order. Clauses in such multiple clause sentences must be logically and rhetorically related. Consider a list to replace an overly complex long sentence.

Tense. Use the past tense for all experimental actions completed in the past including observations or findings of temporary or limited scope. Use the present tense only for findings having very broad and continuing or permanent applicability.

SPECIFIC EDITING AND COMPOSITION RULES

Capitalization of Titles of Exhibits. Consider the unique identifier of every exhibit to be a proper name and capitalize it as "Figure 1" or "Table 2"; but do not capitalize a common name as in "the following figure". Use a consistent capitalization scheme in all titles, captions, or headings. Either capitalize only the initial word or capitalize every main word in every title, caption, or heading. Be consistent in capitalization throughout the report.

Common Typos. Avoid "too" as preposition, "to" as adverb, "it's" as possessive, confusing "form" with "from", *etc.*

Grammar, Capitalization, Punctuation, and Spelling. Use standard grammar, capitalization, punctuation, spacing, and spelling. Simple constructions allow simple punctuation minimizing errors, so write simple and straightforward clauses and sentences. Avoid faulty use or omission of commas. A comma is required with a coordinate conjunction in a compound sentence but not between two phrases that are not complete clauses.

Parentheses. Parenthetical comments almost always disrupt the natural order of sentences, so do not misuse or overuse parentheses. Shun offhand parenthetical comments (even this one). Parentheses prompt the reader that auxiliary or unimportant information is ahead that can be ignored in a cursory reading; therefore, never introduce even moderately important information parenthetically. Conventional parenthetical entries such as 1.0 m (40. in.) are acceptable, but justify any merely clarifying parenthetical comments with a meaningful conventional introduction such as "*i.e.*" for an alternative wording or additional specification or "*e.g.*" for an example.

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CITING AND LISTING REFERENCES

Citing References. Cite every reference by the "author (date)" method. **Never** cite the lab manual; insist on a primary reference that can be cited such as a research or calibration report or a catalog. Minimize secondary references such as textbooks. Use a conventional remark such as "standard texts show" or "texts such as McAdams (1954) state" to introduce commonly known and accepted information. Never ever use an informal citation such as "our thermo text".

Listing References. Listing must include complete bibliographical information in standard format. Use standard form such as for a book: McAdams, W. H., 1954, *Heat Transmission*, 3rd edition, McGraw-Hill, New York. For a report use: Ma, Z., 2000, "Calibration of the Rotameter in ME 4053 LDV Flow Loop", Georgia Tech School of Mechanical Engineering, Atlanta, GA. List literature if and only if cited in the text.

SPECIFIC TECHNICAL WRITING CONVENTIONS

Identifying Equipment. Use the "generic (commercial)" style to avoid "technician speech".

Significant Digits (SD). Never display insignificant digits in text or tables. Measured data has same least significant digit (LSD) as the LSD in its uncertainty (*i.e.*, 314 ± 2 or 27.18 ± .12). Uncertainties can have **no more** than 2 SDs. For routine calculations use the simple **approximate** rules. Specifically, a sum or difference is assumed to have the same LSD as the larger LSD in the two original numbers (*i.e.*, 25 + 273.15 = 298). Further, a product is assumed to have the same number of SDs as the factor with the lesser number of SDs (*i.e.*, 2,718 × 3.14 = 8530). Similarly, the quotient or result of division has the same number of SDs as the lesser number of the SDs of the divisor or dividend (*i.e.*, 27,180 ÷ 31.4 = 866). For **very complicated or very important** calculations use error propagation to determine the uncertainty.

Significant Digits (SD) in Statistics. For statistics, present only enough digits to allow an unambiguous ranking. For examples, $\alpha = 4.997 < 5.000$ for presenting a pass-fail significance test, or $R^2_{\mathrm{QUAD}} = .998 > R^2_{\mathrm{LINEAR}} = .992$ for comparing two Coefficients of Determination.

Units. SI units must be primary. Accompany SI units with conventional units in parentheses when necessary or desirable as in ".3 m (1 ft)" or "1600 m (*ca.* 1 mile)" or "26.6 mm ID (1 in. nominal) pipe". Note the period with "in." for inch.

PREPARING HIGH QUALITY TECHNICAL EXHIBITS

General Features of Exhibits. Employ only the highest production qualities in all exhibits such as figures, illustrations, and tables. Cite (*i.e.*, mention) in the text every exhibit and include every exhibit cited. Provide a unique identifying number and descriptive title. Avoid a perfunctory title such as "Figure 1. Voltage versus Temperature.". Use consistent capitalization style in all table headings, figure captions, and other exhibit titles. Titles must be centered and prominent.

Equations. Equations and other mathematical statements must be accompanied by explanatory text and be created with Equation Editor. Each equation must be centered and numbered. Numbers must be sequential, parenthetical, and flush with right margin. Math symbols must be *Italic*; and notes, function names, and units that are not math symbols must be in regular text style as in "$V_{\mathrm{min}} = 12.5$ m/sec = constant" not "$V_{min} = 12.5\ m/sec = constant$". Equations must be unambiguous and professional in appearance. Avoid E-format and makeshift symbols (*e.g.* avoid "a^2 = a*a"; use "$a^2 = a\ a$"). Use units if needed when numerical parameters are inserted into an equation, such as

$$t_{\mathrm{C}} = \left(R - R_0\right)/\alpha = \left(R - 100.0\,\Omega\right)/\left(0.3850\ \Omega/\mathrm{C}\right) \qquad (1)$$

It may be easier to avoid dimensional equations and stick with symbols. Skip a line before and after every numbered equation. Use control-space to insert needed extra space between symbols in equations.

Graphs and Similar Figures. Emphasize accuracy and legibility. Give special attention to the option of including the zero point on both the vertical and horizontal axes. Avoid all area shading. Avoid extraneous markers, and reserve markers for actual data. Do not connect markers when a scatter plot is needed. Connect markers with straight lines when a profile is needed. A smoothed line may sometimes be appropriate for connecting closely spaced computed points (*e.g.*, points from a theoretical model). Provide a reasonable aspect (*i.e.*, height to width) ratio; don't squash the graph. Do not use a legend for only one series, but always include a legend for three or more series. Provide a unique identifying number and descriptive caption below the graph. The caption title must be somewhat more informative than the mere axis titles.

Lists. Use a list or a table to communicate a long set of related items. All items in a list or table must be rhetorically parallel (*i.e.*, all nouns, all noun phrases, or all verb phrases in one list). Use minimal extra punctuation in either a vertical or an inline list. Indent the list one tap stop (*i.e.*., 1.3 cm) from the left. A symmetrical right indention is a desirable option. A list presented as a separate paragraph or section must have an introductory sentence and should have a closing sentence.

Tables. Give special attention to clarity and consistency. Always include column headers with units. Never display insignificant digits. Use consistent numerical format except when necessary to avoid displaying insignificant digits. Center the numbers in their cells; or better, align the right hand numbers; or preferably, align the decimal points. Provide a unique identifying number and descriptive header. Avoid E-format; use "1.5×10^6" rather than "1.5E6".

Spreadsheets. As an attachment to a report, a spreadsheet must have a unique number and a descriptive title. Title must be centered and prominent. A spreadsheet must have some minimal structure such as blocks for Heading, Summary, Unique Data, and Recurring Data and Calculations. The block of unique data may include constants and parameters and calculations made only one time. Avoid confusing or distracting columns in the General format with variable numbers of digits; so use a specified uniform numerical format as appropriate. A spreadsheet is less formal than a table, but it must have good organization and appearance. Attach a concise block showing cell formulas only when required.