Suggestions for writing design reports

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Summary

Documentation is an important part of the design process. One form of documentation is the written report. The requirements for a report written to document the results of a detailed design stage are discussed. It is proposed that the key ingredients are parts dealing with: the design problem; the proposed solution; and a justification of why the design is appropriate. A fourth ingredient discussing issues of manufacture or implementation is likely also to be necessary.

1 Introduction

A number of models of the design process have been proposed [1, 2, 3]. These attempt to classify the process into a number of stages. Typically these stages move from initial concepts, through various levels of configuration and embodiment design (including associated analysis) to a detailed design. At this stage a proposed design has been created which it is believed can be successful. The next stage in the overall design process is to proceed to manufacture, test and ultimately sell the design.

One key part of the design process which perhaps is not stressed in the various models is that of documentation. It is important to record what has been done. This may simply be because one wants to refer to the design at a future date. It may be part of the archiving policy of a company to ensure that successful ideas can be found and re-used or that earlier mistakes are not repeated. It may also be for legal requirements in order to show that the design was conducted in an appropriate way should faults ultimately be discovered.

Documentation can take many forms. In design it can include: engineering drawings, concept sketches, and CAD models. It has traditionally also included written reports and it is this aspect of documentation that is of concern here.

There is undoubtedly an art to report writing and it is one that can only be developed by practice. A number of guides to writing are available (e.g. [4, 5, 6]). There are also various styles: companies may insist on particular in-house ways of presenting information; academic journals ask for material to be presented in specific forms (e.g. [7]).

The main aim of this report is to propose a structure that can be adopted when writing reports to describe and discuss the results of the detailed design phase of a design project. Section 2 discusses this area in more detail. Section 3 suggests a structure based on the key aspects that the reader wants to know about. The three main aspects are identified and these can roughly categorised as: what is the problem; what is the solution; and why it is going to work. Section 4 goes on to indicate why the proposed structure is appropriate and section 5 indicates how it can be used. Finally some conclusions are drawn in section 6.

Note: The titles used for many of the following sections and subsections make use of the "first person". This is done here to help the explanation and is not recommended for general use: use of the third person is much preferred.

2 What problem am I addressing

The interest here is in reporting on the outcomes of the detailed stage of a design project. It is assumed that a number of concepts have been considered (possibly at an earlier stage in the design process) and from these a final design proposal has emerged. The way in which the design is presented may be in a variety of forms including: engineering drawings, CAD models, physical (scale) models.

As part of the design process, a number of decisions have been made in order to arrive at the final design. Some of these are likely to have involved compromises and indeed the overall specification may have been modified. Presumably those involved in the process has convinced themselves that the design is the best that can be achieved (subject to the known constraints) and that it is likely to work successfully.

There is a need to document what has been achieved. This is partly so that a record is maintained for future reference. In an industrial context, the design report is likely to be used to persuade others that the project has been successful and that the company should go ahead and make the product. The report might also be issued to potential customers to gain their approval. In the academic context with projects undertaken by students, the report is used as a basis for some of the assessment.

In all these cases, there is clearly a need to explain well and simply what has been done, what has been achieved, and what recommendations are proposed for future action (if any). So the question is: what form should the design report take? This is considered in the following sections.

3 What my solution is

It seems obvious that people reading a design report are going to be interested in three basic things: what is being designed; what the design is; and why it is going to work. There is also an additional issue which is slightly less obvious. This is whether the proposed design can be manufactured or implemented.

With this in mind a structure for a design report is now proposed. There are six basic parts. These are discussed the following subsections and they are summarised in figure 1. Note that this does not necessarily imply six sections in the report; it might be necessary to add other sections or combine some parts into one section. If a report is to cover two or more separate aspects, then it seems sensible to consider each one in turn and so repeat some of the parts for each aspect. The "titles" suggested certainly should not be used. The style for reports [8] suggests that the third person should be used, so the use of "I" is not allowed. Attention here is paid mostly to the main body of the report; material such as a summary, references and appendices may also be needed.

Introduction

Clearly the report needs an introduction which sets the scene. This should give an overview of the design task and what has been achieved. Someone who does not know about the design project ought to be able to read the introduction and obtain a good feel for what has been done without having all the details. It is usual also for the introduction to explain the structure of the report. So phrases such as "section 2 describes ..." and "section 3 discusses ..." are common.

If the report represents one aspect of a larger project (and there are one or more other reports explaining the overall issues), then there is no reason for repeating general material about the full project. Instead the report should concentrate on giving an overview of the particular area that is being dealt with.

There is an argument to say that the introduction should be written last. At least then one knows what one is introducing.

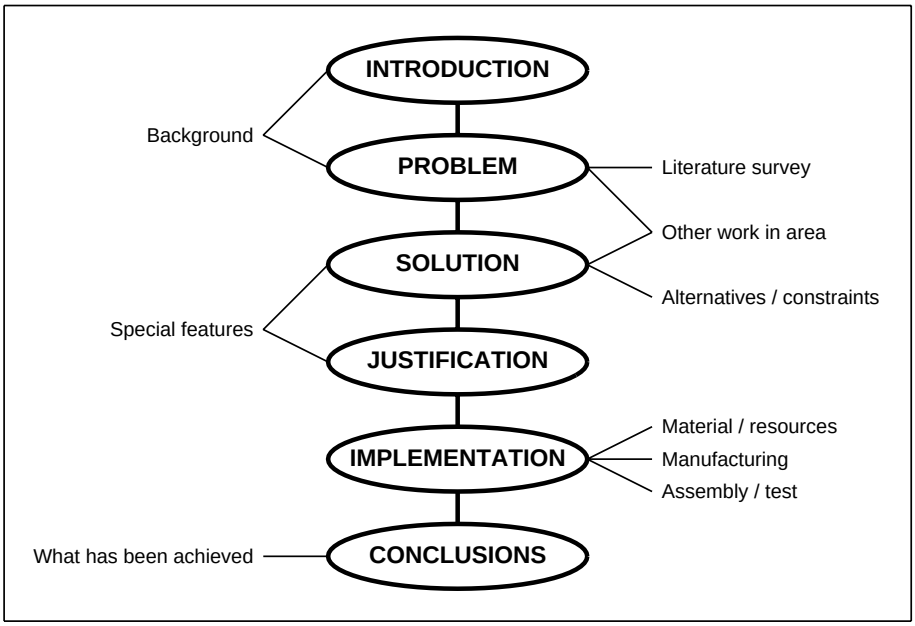

Figure 1: Suggested structure for report

Problem: what problem am I addressing

There seems little point in explaining what one's design is without first explaining what problem one is trying to solve. This needs to be succinct but carry all the details. It should be possible to assume the reader is intelligent and has a basic understanding of engineering and design. However any specialised ideas or terminology need to be defined and discussed. It is here that references to external material are likely to be required. It may also be appropriate to indicate what constraints exist on possible design solutions.

Solution: what my solution is

It is obviously vital to say what the proposed design solution is. Diagrams (or other illustrations) can help greatly here. However it is sensible to explain what these mean in the main text. Without this, readers are forced to work out what the diagram means for themselves and they may arrive at an interpretation different from that intended. Worse still, they may have to think about the design for themselves and, in the process, find reasons why it does not work. So an explanation needs to be more that a statement such as: "figure 5 clearly shows the design".

Good use of labels on a diagram can facilitate the verbal description. It is also helpful to the reader if the diagrams appear in the main text at around the point where they are discussed. Key diagrams should therefore not appear in appendices. If a CAD model of the design has been created, the diagram for the main text can be generated from this (as well as any full engineering drawings that might also be required).

Justification: why I believe my solution works

In arriving at a final design a number of decisions are likely to have been made. The designer presumably has become convinced that the design is going to be satisfactory. These reasons need to be documented.

The justification for the design may take a number of forms, including one (or preferably more) of the following.

- It *obviously* will work: it is clear from everyday experience that it is satisfactory; however what is obvious to one person may not be to another.
- An acknowledged *expert* says it is appropriate.
- It is very similar to an *existing design*: but then there may be issues of plagiarism and infringements of patents to consider (and appropriate references probably need to be made in the report).
- Appropriate *calculations* have been done: rough estimates may be appropriate if they show what is required.
- A *CAD model* has been produced and shows what is required: perhaps that parts fit together correctly.
- An *animation* has been produced and shows what is required: perhaps that a mechanism cycles without clashing.
- A *computer model* has been used to predict performance: such computer work might include finite element analysis or computational fluid dynamics.
- A *prototype* or *model* has been built and tested: the report might show photographs of what has been done.

Implementation: how I would make/implement my solution

In the case where the design of a mechanical part or system has been undertaken, this aspect is essentially one of how the design is going to be produced. Issues that need to be discussed include: choice of materials, manufacturing processes, inspection (and verification), and costs.

Conclusions

Here the main parts of what have been carried out certainly need to be summarised. One conclusion is going to be that "whatever it is" has been designed. Another is likely to be about the appropriateness of the design. How closely does it meet the design requirements? Is it good, bad, or just about workable? Notable features of the design might also highlighted and their suitability indicated. Whatever is said in the conclusions should repeat or follow directly from previous sections of the report. No new material (or external references) should be introduced: that should included earlier on.

4 Why I believe my solution works

In order to assess the suitability of the report structure proposed in section 3, a study was undertaken. This carefully avoided any of the approved standard experimental approaches that can be classified as design of experiments [9, 10].

	Description	Number	Av. age
A	Primary school children	20	6
B	Undergraduate engineering students	20	19
C	Postgraduate engineering students	20	23
D	Engineering academics	10	48
E	People in a bus queue in central Bath	20	58
F	Senior executives in large engineering companies	10	67

Table 1: Groups involved in assessment study

Instead the proposed structure was shown (or, in the case of group E, sent via e-mail) to five groups of people. They were asked to score it on a five point scale. The groups labelled A, B, C, D, E are detailed in table 1. This also gives the number in each group and their (estimated) average age.

Table 2 shows the results from the survey. The scores against each of the five categories are shown, together with the number of unclassified (inappropriate) replies and the number of non-replies. The score in the final column is the average score (using bad=1 and excellent=5) over the appropriate responses received.

Group	Bad	Poor	OK	Good	Ex'ent	Unclassified	Non-replies	Average
A	0	1	1	0	0	18	0	2.5
B	0	4	6	8	2	0	0	3.4
C	2	2	4	8	4	2	0	3.6
D	0	0	4	0	0	0	6	3.0
E	0	1	1	0	0	16	2	2.5
F	0	1	0	0	0	0	9	2.0

Table 2: Summary of responses to assessment study

The results suggest a consistent variation in the average response with age. It was assumed that this relation is quadratic and takes the form

$$r \;=\; a \;+\; bx \;+\; cx^2 \tag{1}$$

where r is the (average) response, x is the average age of the group, and a, b, c are constant coefficients. Least squares fitting [11, 12] was used to determine the coefficients in equation (1). If there are n data points comprising pairs of values (x_i, r_i) for $i = 1, 2, \ldots, n$, the least squares approach is to assume a form for the relation, equation (1) is used here, and then to try to minimise the following expression

$$E \;=\; E(a,b,c) \;=\; \sum_{i=1}^{n} (a + bx_i + cx_i^2 - r_i)^2 \tag{2}$$

which represents the sum of the squares of the "error" between the assumed expression and the actual value at each data point. At a minimum, the partial derivative of E with respect to each of the coefficients a, b, c is zero. Forming the derivatives of equation (2), setting these to zero and rearranging leads to the following matrix equation for determining the coefficients.

$$\begin{bmatrix} n & \sum x_i & \sum x_i^2 \\ \sum x_i & \sum x_i^2 & \sum x_i^3 \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \;=\; \begin{bmatrix} \sum r_i \\ \sum x_i r_i \\ \sum x_i^2 r_i \end{bmatrix}$$

In the case of the results here, the least squares approach yields the following values.

$$a = 2.16 \qquad\qquad b = 0.0859 \qquad\qquad c = -0.00135$$

A graph of the corresponding curve given by equation (1), together with the original data from tables 1 and 2 is shown in figure 2. This suggests that the proposed structure is more than acceptable for people between the ages of 12 and 50. Furthermore, it does not slip below "poor" until people reach retiring age at 65.

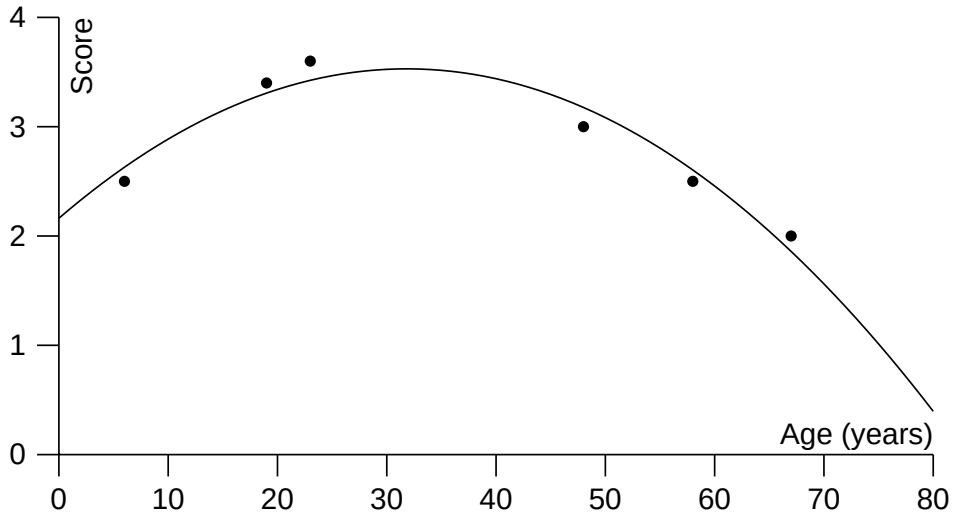

Figure 2: Graph of response against (average) group age

5 How I would make/implement my solution

The implementation for use of the proposed structure is straightforward. One starts by obtaining access to a word processor (or similar tool) and begins by writing those parts associated with the "problem". Indeed this part could be undertaken before or during the actual design activity.

Once the design has been established, those parts dealing with "solution", "justification" and "implementation" can be tackled. Not only text is required here, but also suitable diagrams need to be incorporated.

Finally, the introduction and conclusions sections can be dealt with.

This completes the basic report. It is of course necessary to add a summary, if one is required. The references can be built up during the rest of the writing process.

6 Conclusions

It has been seen that documentation is a crucial, integral part of the design process. In particular, once a design has been completed then is a need to report on what that design comprises and any assumptions that underlie the decisions made. Reports need to cover all the essential points and yet be succinct.

It has been proposed that there are four key parts as well as the introduction and conclusions. These are: problem, solution, justification, and implementation. It is important for the reader to know what problem the design seeks to solve. The proposed solution needs to be explained well and also why it is believed the solution is appropriate. Additionally it is often necessary to indicate how the design is to be manufactured (or otherwise implemented).

Initial trials to assess the proposed structure have been undertaken. The results are encouraging, though possibly more work in this area needs to be undertaken.

Finally it is worth noting that this report itself follows the proposed structure. While it is hardly a typical "design report", this does at least show that the proposed structure is usable.

References

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Appendix 1: Use of appendices

The word "appendix" has a number of meanings. In the sense that it is used here, *The Chambers Dictionary* gives the following definition:

> "an addition to a book or document containing explanatory matter, not essential to its completeness" [13]

Appendices are a useful way of providing additional information. However it ought to be possible to throw the appendices away and still be able to read and understand the main text.

The sorts of additional information for design reports can include some of the following items.

- Detailed calculations leading to results which are stated in the main text
- Descriptions of design alternatives which were investigated but were discarded
- Fuller lists of experimental results which might appear simply as graphs in the main text
- Fuller lists of suppliers and their components as alternatives to much shorter lists in the main text

As it is part of a formal report, an appendix should not simply be a "rag-bag" of items. It ought to have some structure and there ought to be some introduction saying what the purpose of the appendix is and what information it contains.

Additionally, if the appendix is presenting calculations, then the notation needs to be explained (or the reader referred to the explanation in the main text or elsewhere). Similarly, an alternative concept needs to be more than just a diagram; some words of explanation are required.

Appendix 2: Some thoughts on style

To some extent the style of writing is a matter of personal taste. However some companies and other organisations have their own in-house rules about how things should be written. For example, the Department of Mechanical Engineering at the University of Bath issues guidances notes for writing laboratory reports [8] which it expects to be carried over for the writing of other reports. Academic journals also issue style guides for authors. This includes those issued [7] for the various parts of the Proceedings of the Institution of Mechanical Engineers.

The following list makes suggestions on essentially minor points of style but which are a source of irritation for some more pedantic readers. Some points on grammar are also noted [17].

1	Without care it is easy to end up with a mixture of tenses in a document. This can be confusing to the reader. Use the past tense when reporting on events which have definitely taken place. For example: "A CAD model was constructed and this allowed a simulation of the motion of the guidance mechanism to be obtained. It was discovered that clashing occurred between the end-effector and the main support strut". Try to use the present tense for everything else. For example: "It was found that when the size of the end-effector is less than 10mm such clashing never occurs".
2	Use an impersonal style: write in the *third person*. Avoid the use of "I", "we", "you", "our" and so on. Often these can be avoided by simply switching the order of a few words in a sentence, and this becomes easier with practice.
3	Avoid contractions such as "don't", "can't", "wasn't"; the full words are preferable. Note also that "can't" expands to "cannot" which is one word.
4	The word "its" meaning "belonging to it" does not have an apostrophe. The word "it's" (with the apostrophe) is a contraction for "it is" and should be avoided (see above).
5	All figures and tables should be numbered and have a suitable caption. They should also be referred to (at least once) in the main text. Do this using the number, for example: "... and the results are shown in table 3 and given as a graph in figure 5". Avoid constructions such as: "... and the results are in the table below"; by the time the word processor has decided to reformat things for you, the table could be anywhere.
6	One of the uses of the colon (:) is to introduce a list. For example: "Caesar undertook three actions: he came, he saw, he conquered". Despite many (erroneous) contemporary examples, the semicolon (;) does not have this role.
7	Select a (simple) convention for numbering sections and subsections and stick to it. It is usual not to number a summary or a table of contents. Decide also on a convention for capital letters in section headings: only at the beginning the first word; or at the beginning of every main word. It is remarkably easy, as a reader, to notice inconsistencies.
8	Avoid excessive use of capital letters at the beginning of words in the text. They need to be there for words which are definitely proper names (or derived from them) such as with: "Hooke's law", "Brownian motion", "University of Bath". Materials, such as "aluminium" and "steel", do not have capitals unless they are specific trade names.
9	Do not feel obliged to put capital letters at the beginning of words which are going to form an acronym. For example, the following is quite acceptable: "A number of techniques have emerged recently including: computer aided design (CAD) and finite element analysis (FEA)".
10	Avoid footnotes. Before the use of word processors (and similar software), footnotes provided a means for inserting additional text without having to re-type (or re-set) the document. Such insertions can now be handled easily with computer-based tools and footnotes are no longer needed (at least for engineering and scientific documents).

Appendix 3: References

If a design task is to be undertaken properly, external sources need to be consulted. These are likely to include: standards, design guides, catalogues from suppliers, text books, and research papers. When the design is documented, these sources need to be referred to. This is partly as a record of where the material came from, and partly so that the reader can find further details should this be necessary.

A lot of material is available easily via the Internet. However, there are potential problems here. There is little or no editorial control over what material appears in web pages. So there is no guarantee that the information is correct. Another difficulty is that web pages frequently disappear (and reappear with different content or with different web addresses). This means that referencing a web page is of little use within a report that is intended as a means for documentation that may itself by referred to after some time.

So, if it is at all possible, it is greatly preferable to reference material that is available in printed form from a reputable publisher.

There are two main ways of referencing. The *numerical* version is the one used in this document. Each entry appearing in the list of references is given a number. The reference is then made by indicating that number in square brackets (or round brackets or as a superscript). The entries in the list of references normally are given in the order of the occurrence of their first use in the main text.

The alternative is the *Harvard* system. The entries in list of references are not numbered and they appear in alphabetical order of the surname of the first author. The citation in the main text is by the author(s) and year. For example, the book by Pahl and Beitz [1] is cited as (Pahl and Beitz, 1984). If the Harvard system is used, it is normal in the entries in the list of references for the year to be given immediately after the names of the authors (rather than towards the end of the entry as is the case in this document).

The Harvard system has two advantages. Firstly, if a new reference needs to be added, it is simply introduced into the list at the appropriate alphabetical position. There is no need to renumber subsequent entries. Secondly, a reader familiar with the relevant literature can recognise the reference when it is cited by author(s) and date without having to consult the list.

The numerical system is used in this document because the Latex type-setting package [14, 15] has been used. This allows references to be made (in the source files) via labels. These are replaced by the appropriate numbers when the text is formatted. This means that it is simple to carry out additions and the appropriate re-numbering is done automatically.

More information on referencing is available from the library at the University of Bath [16].

If a picture comes from an external source, then of course this needs to be acknowledged. It is suggested that this is better done by giving a normal reference (number or author-date) in the figure caption (and possibly the main text as well), and putting the full details in the list of references. This avoids trying to squeeze the full details into the caption.

Some people make a distinction between "references" and a "bibliography". The latter seems to be a list of items which have been read but not actually referenced. It is suggested that only the list of references should appear. If there is a need to make note of material in a "bibliography", then it should be simple enough, in the introduction, to include a sentence such as "The problem of ... is an important one in mechanical design [2]" and thus make a proper reference.