# A 'THEATRIC' APPROACH TO THE TEACHING OF DESIGN

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## ABSTRACT
Design teaching is complicated due to its context specific nature. The teaching of it as an academic subject focuses on the core technologies of embodiment, detailing and manufacture. In order to put these into context issues that establish the background and also the success of the design should need to be considered. These are expressed here in theatrical terms as providing the prologue and epilogue around the main 'play'. The prologue establishes the background and sets the design into the specific nature of the problem being handled through an understanding of the broader issues of the originality of the problem, the frequency with which it has been addressed as well as the current exploitation and commercial application. The epilogue is often ignored during teaching as the solution is expected to follow the core processes and lead directly to a solution. In 'real' design there is often the case that the chosen solution may not meet all of the requirements or the original brief may have failed to cover items that subsequently turned out to be important. The inclusion of these additional aspects of design during teaching allows the context and core issues of design to be better understood.

*Keywords: design teaching, context nature, design processes*

## 1 INTRODUCTION
The teaching of design in further and higher education establishments is highly complex due to the context specific nature of its activities, and has attracted much research over the past decades (e.g [1-3]). The activities undertaken in real life, whilst fitting within a common general framework of techniques, will vary widely dependent upon the environment, social conditions, business and organisational framework in which the design problem is cast. Whilst the technical nature of the problem may appear to be similar, the approach adopted, and outcome can vary widely as the background issues change [4]. For example when considering the design of a coupling to link a trailer to a towing tractor, many of theses issues need to be considered before any design work can commence. If this is simply an emergency solution to pull the trailer out of a ditch, it will be approached differently to that of an international tractor manufacture wishing to increase its product range and include a new linking device in its catalogue. In both cases the 'core' activities will be the same and need to consider the geometry of the attachment device, its strength and its safety. However other issues such as its cost, commercial potential and manufacturing issues may not be readily considered in the emergency recovery situation. Here the main issue that drives the choice of solution may be one more based on availability. Do we have a chain that 'looks' strong enough that can be attached to both strong points on the trailer and tractor? If time and analysis is available some simple calculations may be undertaken to assess the strength of both chain and attachments. Additional safety issues may be put in place, such as moving people from the area in the event of failure and providing blocks and wedges to stop the trailer rolling back. Once the core activities have been completed the design is often considered to be finished. In reality this is not the case. There is then the necessity to ensure that the completed design fulfils all of the requirements and actually works. All too often in this concluding stage it is realised that something of importance has been missed and further redesign has to take place. It is also important that the designer uses this activity to assess the effectiveness of what has been achieved and to understand how it could have been done better. Time spent on evaluating what has been achieved, its cost effectiveness, its manufacturability and its acceptability as a product, or solution, are all worthwhile activities that will improve designs in the future.

## 2 DESIGN TEACHING

With such complexities, created from the context of the design problem, it is not surprising to find that the majority of design is taught only around the core technical issues rather that in it full context. Students are thus taught to generate geometric models and schemes that can then be analysed, to see whether they are compatible with a given design specification or brief. Design is then seen by the students as undertaking a systematic piece of analysis rather a full problem solving activity, in which all of the other issues impinge.

Design can not be undertaken within an abstract environment, but must be set within a realistic framework, such as one in which a theatrical play is set in order to tell a story. Bursting into the middle of a Shakespearian play, without an understanding of the characters, the setting or the plot line leaves the observer with no idea of how the plot will unfold or the objectives to be achieved. Similarly the designer is unable to construct a background or an objective by simply observing a few stages of a design procedure or understand their relevance to the overall success of a developing design. Similarly it is only when these elements, encompassing the design, are understood can the relevance of the main activities be determined and the activities be put in place. The elements to be employed in the approach will be dependent upon how common is the ‘plot’. Had the type of design become familiar then the design activities will be readily recognised, otherwise it will be necessary to return to first principles and the elements of this design need to be discovered.

### 2.1. Background knowledge (or Prologue)

No design can start in a void. There is not only an objective but also some awareness of its possible achievement, which may in its first presentation be less than perfect.  This awareness is based upon previous experience of the designer or the team. It may arise from the experience (both positive and negative) of an individual. It may occur from the collective knowledge of a team or be perceived through the collective wisdom of published works of the whole community. The extent to which this experience exists and it’s relevant to the problem is again dependent upon the familiarity of the designer with the problems in that type of design. If the background has been well documented it may well become a familiar place from which a design team may approach or even be considered, within the organisation, as the ‘correct’ place to start. Here the danger exists that such an approach to the generation of the background may include elements and requirements that no longer apply. Activities and assumption will then be incorporated that will both mislead the design direction and add processes that need not be undertaken.

### 2.2. Elements of the prologue

In establishing the background to any design problem it is necessary to address the originality of the problem being address. The current available knowledge on the subject should be searched. This may included many of the following: technical publications, commercial information, patents, books, journal and catalogues and practical examples. These will provide an understanding of ‘how original the problem is’. If there is a great deal of commercial information it is unlikely to be original and solutions can then be readily sought by studying what has been done before. Technical literature will establish the principles upon which solutions may be sought. Often the finding of an example that has been tried before will give a good understanding of the problems to be addressed. Finding a working example, when the subject is being taught is thought to be ‘cheating’, however in real design work it is often a good place to start (when working on a new design of bathroom scales one of the authors was involved in buying and analysing over one hundreds of such products).

The prologue thus provides the designer and team with the necessary understanding of the problem, what exists, what the competition is and whether it is worth carrying on. On occasions when investigating a design proposal for a client it may be better to say that it is unlikely to be successful for good reasons than to enter into a design study that can not succeed. This may be due, amongst other things, to the ideas being covered by patents, a competitor is already delivering the product, the technology necessary to make it work is too advanced or the investment is likely to be too great.

## 3. CORE DESIGN ACTIVITIES

Having understood the background and objectives the necessary element in the solution of the design problem can only then be considered and formed into the related' acts' and 'scenes' that make up the process. Whilst most designers can agree on most of the basic 'acts' which make up the processes, not all are usually included within each design method presented. This is often the result of the creation of a procedure that has been observed during the execution of a particular class of design activity. The main body (or core) is thus seen in most methods as a trail of connected activities that leads from the objective through to a successful conclusion. Similarly the main body of a play leads the audience progressively from the prologue through to the epilogue. This passage should be both complete but may well include some surprising twists and turns. It should not, in design, result in irrelevant activities but should pursue a 'pathway' that can be followed by other seeking to undertake a similar design. It is not unique but case dependent. Some designs need to arise directly out of the study of form and market requirements, with little need initially to undertake any analysis. Conversely the design of a high-tech device such as an aircraft will commence with a highly detailed analysis of its performance and structural strength, together with a conformation that it will meet the regulations under which it will operate commercially. The core processes, whilst extending the activities from feasibility, through detailed embodiment to manufacturing, may be adapted by changing the order and importance of these key elements. Early on it may be necessary to establish the manufacturing capability of the organisation to ensure that detailed designs can be made or bought in.

### 3.1 Core teaching elements

In the many design methods that exist in the teaching of design, all are comprised of these three core elements (feasibility, embodiment and manufacture) though some may use different terminology and emphasise different aspects, but can be grouped as follows.

#### *3.1.1 Concentration on main body*

VDI (Verein Deutscher Ingenieure) is the German professional engineer's body. This has produced a number of guidelines in the area of design. The VDI design handbook [5] describes a systematic design methodology, as shown in figure 1a.

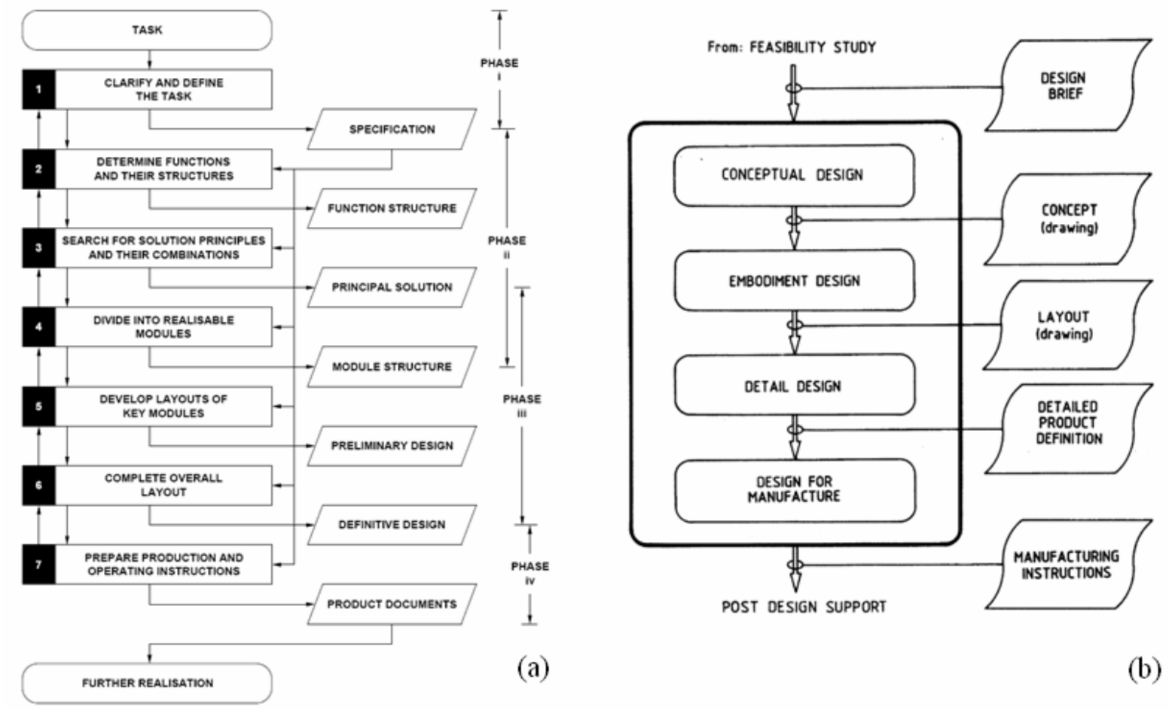


*Figure 1 VDI [5] and BS7000 design model [6]*

The stages in the VDI 2221 (cf. figure 1a) model are: *Clarify and define the task* where the resulting specification is shown to feed into every subsequent task. *Determine functions and their structures*, the overall function and the most important sub-functions are derived from the specification. These sub-functions may be combined into a 'function structure', as a basis for the search for solutions. *Search for solution principles and their combinations:* Having identified the sub-functions, the next stage is to *identify solution principles*. If new solutions are necessary, then these are found by searching for suitable principles, or physical effects. An initial consideration of the materials, geometries and motions for these new solution principles is also required. The solution principles for each of the sub-functions are then combined in accordance with the function structure to result in a principal solution (or concept). *Divide into realizable modules*: The principal solution is broken down into separate modules. This may be to facilitate the working principle, ease of assembly, maintenance, recycling and/or product variations. *Develop layouts of key modules*: During this stage, the key modules are arranged, and the main dimensions estimated to give a preliminary design. Detailed information about the layout is not added at this stage, because optimization has not taken place. *Complete Overall layout*: Detailed information is added to the preliminary design, including standard modules that would not be included in the previous stage. This stage results in a definitive layout containing all of the essential configuration information. *Prepare Production and operating instructions*: A set of product documents, such as detail and assembly drawings, parts lists and testing instructions, is produced based upon the definitive layout. Pahl and Beitz [7] which is based on [5] and divides the design process into four stages. The state of the design at the end of each stage is included in the model, as well as the activities or steps that are required to reach this state. The process begins with a task. The first stage is to *plan and clarify the task*, resulting in a requirements list. The second stage is *conceptual design*, which seeks to find the main principle solution of how the product will function resulting in a concept. The third stage is *embodiment design*, which develops the concept, leading to a preliminary layout midway through this stage, and a definitive layout at the end of it. The final stage is *detail design*, resulting in product documentation and a solution.

BS 7000 [6] includes a model of the 'idealized design process', derived largely from Pahl and Beitz. In this model, a feasibility study is assumed to have taken place, and the process starts with a *design brief*. This design brief is a set of requirements for the design. This is followed by *conceptual design*, in which group working or brainstorming is used to generate alternative proposals that are evaluated against the design brief. In the next stage, *embodiment design*, four objectives are identified: formation of the layout or general arrangement, identification and examination of risky or difficult areas, production of models if required and consultation with other company functions e.g. manufacturing. This is followed by a *detail design* stage. Here, the final details of the design are added. The importance of involving other company functions is emphasized again.

#### *3.1.2 Problem identification/need*

One of the first authors to model the design process as a series of discrete stages was French [8]. His model is shown diagrammatically in figure 2a. As the design solution is refined, the design process moves through these stages sequentially. From a starting point of the design requirements, the first stage of activity (signified by a rectangular box) is the analysis of the problem. This activity results in a statement of the problem. The statement is broken down into three elements (not included in the diagram); a formal statement of the problem, limitations placed upon the solution (i.e. requirements) and criterion to be worked to (targets for cost effectiveness). The second activity is conceptual design, during which ideas are generated and potential design solution schemes emerge. The conceptual design activity may result in further analysis of the problem, as indicated by the feedback loop. The refinement of selected schemes are broken down into two further activities, embodiment and detailing. The detailing activity results in working drawings that are considered to be the end result of the design process, as they provide sufficient information to enable manufacture.

Ray [9] describes the stages of the design process, based upon the life cycle of a product (cf. figure 2b). As in French's model, the refinement of the solution passes through a number of discrete stages. The first stage, 'Identifying the problem', consists of identifying a requirement of society and forming a specification or 'brief'. This is equivalent to the need in French's model. There is no analysis of the problem, although this is partly addressed in the 'feasibility study'. The aims of this are to ensure that it is physically possible to produce the product, that it is economically viable and acceptable. This is followed by 'preliminary design', in which several alternatives are developed and then compared. The preferred solution is then fully developed in the 'detailed design' stage. This development can include the production of a scale model or working prototype. The outcome of the detailed design stage is a fixed design concept. In this model, the stages are the same as described above, with feedback loops added from each stage to every previous stage. Ray then describes three subsequent 'planning stages' that are distinguished from the previous 'design stages'.

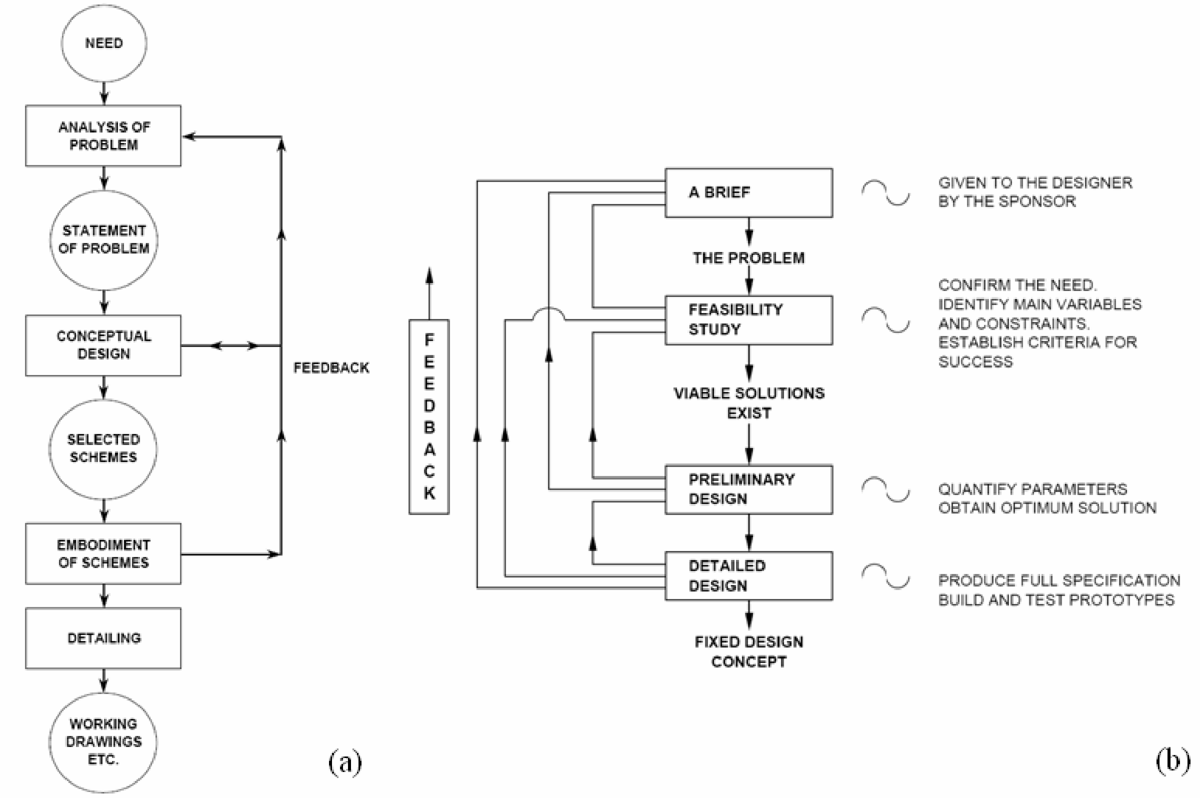


*Figure 2 French [8] and Ray [9] design models*

#### *3.1.3 Partial prologue and partial epilogue*

Archer [10] breaks the design process into six stages, although he acknowledges that they are often overlapping with frequent returns to earlier stages when difficulties are encountered. Figure 3a is a combination of two models of the design process by Archer, showing both feedback arrows and details of the three phases. The first two stages, 'programming' and 'data collection', form the 'analytical' phase. In this phase, observation and measurement takes place, followed by inductive reasoning. This is followed by the 'creative' phase, which comprises the 'analysis', 'synthesis' and 'development' stages. Each of these is linked by feedback arrows to data collection, recognizing the importance of information throughout the design process. Sub problems are identified within this creative phase, and design proposals are developed with the best one being selected. The final, 'executive' phase consists of one stage, 'communication', in which the documentation necessary for production is produced. Pugh [11] describes the 'design core', the central activities that make up the product development process, as shown in Figure 3b. Pugh makes the case that any design activity begins with a market need, followed by the formulation of a product design specification. Within the envelope of this specification, the subsequent stages of concept design, detail design and manufacture take place. The final stage in the process is then selling. Pugh asserts that the main design flow is iterative, giving the example that a concept may emerge after reaching the detail design stage. This is only represented by the backwards arrows in the model. He then adds discipline dependent design tools such as thermodynamic analysis as well as independent tools, applicable to any discipline, such as for decision making or modelling.

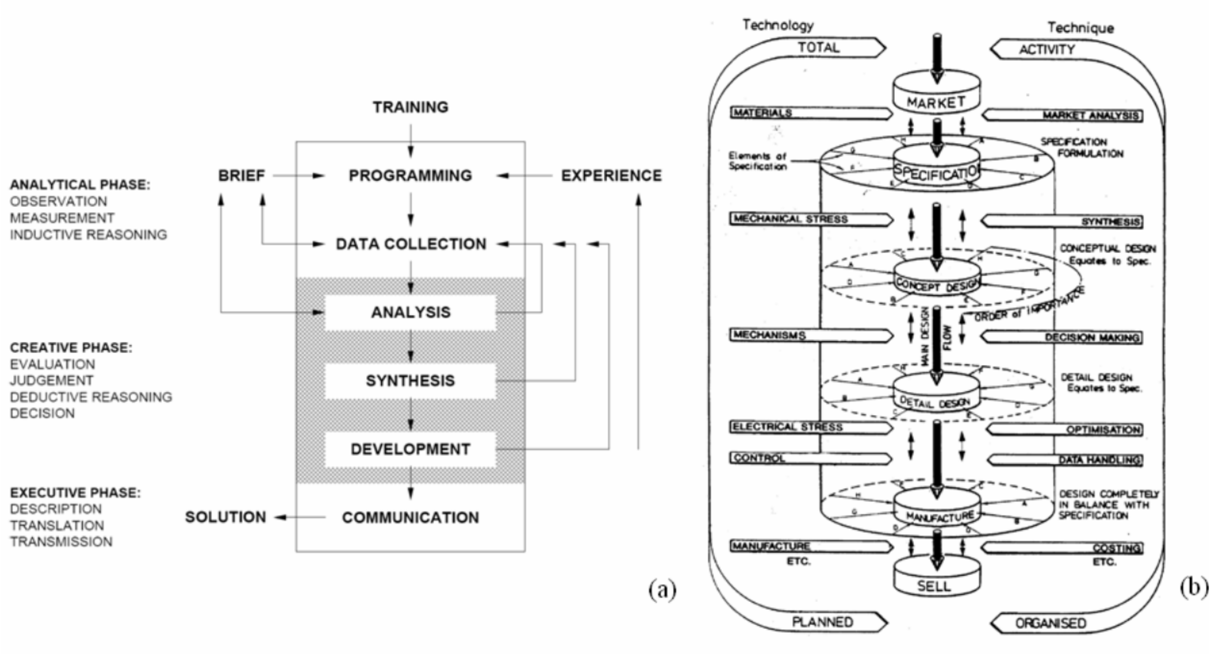


*Figure 3 Archer [10] and Pugh design models [11]*

### *3.1.4 Prologue and epilogue structures*

Matchett's model [12], aims to map the pattern of the designer's thoughts and to relate this pattern to the design process, the model of which is shown in figure 4a. Despite its unconventional appearance this is a systematic model of the design process. It starts with the definition of the problem. This is then split into six thought dimensions; time, reason, means, place, need and method. The design progresses from this initial problem, within each of the thought dimensions, through phases of establishing the factors and their relationships satisfying these needs by principles and then form. "Judgement planes" located between each of these phases represent judgements in an upward direction and decisions in a downward direction. The aim is to reach an optimum solution meeting the sum of needs within each of the six dimensions. The addition of a number of different viewpoints is intended "to keep the problem and the objective of solving it constantly in mind".

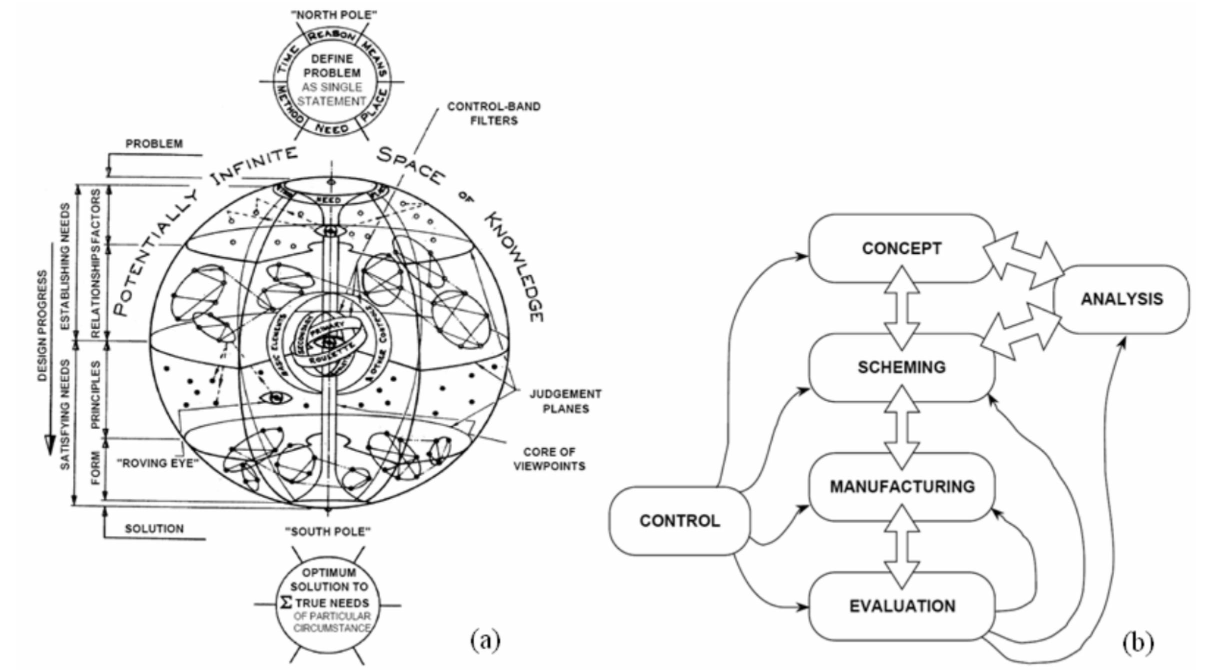


*Figure 4 Matchett's [12] and Medland [13] Design model*

#### *3.1.5 Evaluation of solution*

Medland [13] divides what is usually referred to as the 'anatomy of design' into six stages, as shown in figure 4b. The four stages at the core of their model are similar to those in both French and Ray's models, although the problem is omitted. The process instead starts with a 'concept' stage followed by 'scheming', which is equivalent to embodiment and detail design in the other process models. The model then progresses through a manufacturing stage and ends with an evaluation of the final product. As with the previous models, feedback loops are included, in this case from the evaluation stage back to manufacturing and scheming. These core stages are supported by two extra, parallel stages. An "analysis" stage, may either be used for analysis of the conceptual design in order to "provide the necessary details for scheming" or alternatively to check that the result of the scheming stage meets the original requirements. The "control" stage shown in the model is to "organize and coordinate" all of the other stages. Having established these elements of the design process, the effect of the type of product on the relative importance of each of them is then discussed. Medland distinguishes between 'over-constrained design' where the design activity is one of optimization by satisfying conflicting constraints, and 'under-constrained design' where the design activity is one of selection.

## 4. THE CONCLUSION (OR EPILOGUE)

The conclusion (or epilogue) of the design should be well constructed and evaluated to ensure that all objectives originally set are met. This must provide an understanding of all analysis, processes and procedures by which the design was be successfully achieved. Often it is assumed that if the design meets all the requirements in the original brief, it has been successful and no further investigations need to take place. This may not be the case. It is difficult to assess risk and safety until a design is complete as these issues may well be highly dependent upon the fine detail of the design itself. It may also be difficult to eliminate them (except at great expense) once full manufacture has been undertaken and tooling committed. A completed design is also a commitment to future activities of the company. Before moving into this a clear decisions should be made as to whether it is the right one:

- Is the market really there?
- Can the company provide the resources and commitment necessary to achieve a success?
- Can it fight of competitors?

It should not be assumed that success naturally follows a good design.

### 4.1 Teaching elements of the conclusion or epilogue

The epilogue is an activity in which all aspects of the completed design are considered in the light of the original requirements. It is not always in real designing that the problem has been fully and successfully addressed. Here it is necessary to consider whether sufficient has been achieved that would warrant a continued commitment of time and resources. An investigation needs then to be conducted into the commercial potential and technical issues that still need to be resolved. Within the framework of design teaching it is sufficient to require that the students undertake a critical assessment of what has and has not been achieved:

- Will the design ever meet its technical objectives?
- Can it compete commercially with existing products?
- It there a better approach?

All of these are very difficult to answer truthfully but are the one that one is asked to comment of when undertaking a real design activity and are usually demanded in a final report to the Board.

## 5. CASE STUDY – LABELLING MACHINE FAILURE

A case study (cf. Figure 5) has be chosen from a real consultancy activity which was dominated by it prologue activity, contained only to (simple) loops of the core designing and was seen to be successful (by the client) by its thorough epilogue activity.

### *5.1 Prologue*

- *A machine, designed on the east coast of America, failed on the west and in the process cut off the operator's hand:* This was a consultancy request from a client that was facing legal action due to injury of their customer’s employee. Once a contract was agreed for investigation a consultant was sent to the USA to investigate with instructions to only return when the problem was solved.

- *Due to the distance, location and severity of the accident little evidence was left on site to analyses the cause of the problem:* Very little data was available about the accident, the operator’s condition and the state of the machine. There was no opportunity to visit the site of the accident as it had all been ‘tidied away’
- *As a label carriage had fallen, trapping the hand, the conclusion was drawn that the dog clutch driving it, had failed:* The only available information, obtained from an accident report, was that a hand was trapped and lost as a loading carriage fell at the time the operator was inserting a new stack of labels. It was assumed that the dog clutch, used to lift the carriage had failed.
- *Extensive redesign of the clutch was undertaken but the failures continued (when investigated in the client’s factory):* The redesign activities included changing the number and angles to the teeth on the clutch. A number of new clutches were designed and built. These were then installed in a machine located in the client’s factory and fully tested. Each design was seen to eventually fail.

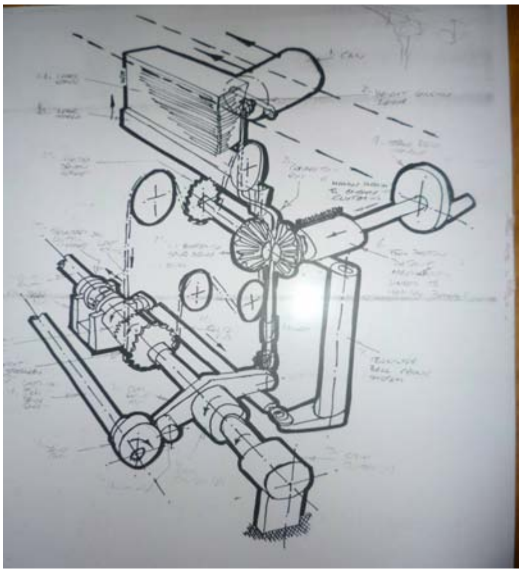

*Figure 5. Sketch of operating linkage of labelling machine that failed (taken from the investigation logbook and made on site)*

### 5.2 Core

- *First loop - Detail study of available information:* On arriving at the client’s factory the machine, its mechanism (shown in Figure 3) and the various redesigns, were all investigated and recorded. Accident report was also read.
- *Detailed analysis of clutch geometry:* The geometry of the dog clutch was modelled and analysed to calculate the forces moving the teeth apart against the friction forces.
- *Analysis of modes of failure:* All designs were investigated and their possible modes of failure identified.
- *Establishment that clutch could not fail:* The analysis of the friction forces separating the teeth showed that, once engaged, none of the clutch designs would fail.
- *Experiment undertaken to confirm conclusions that clutch was not the cause:* The available clutches were mounted in a machine that was set up in the client’s factory. Each was engaged and the extent of tooth interlock recorder. With the machine running the carriage position was locked. On each occasion the machine stalled rather than have the clutch fail. This established that the failure was not caused by the clutches.
- *Second loop - Investigation of drive linkages to close clutch showed possible failure due to ‘stretching’ between joints:* This investigation showed that, with the machine turned off, it was possible to force the clutch linkage mechanism into its engaged position whilst the clutch was not engaged. This was the result of stretch and flexibility in the linkage train.

- *Solution proposed in the form of a clutch closing spring arrangement:* The possibility of the two clutch halves resting crest-to-crest should have been low with good alignment but when forced in distortion occurred and the moveable half locked upon its shaft. When the drive shaft indexed forward no engagement occurred and the label carriage fell causing the accident.
- *Closing arrangement built:* Whilst consideration was given to a redesign of the whole drive linkage, a simple solution was found by providing a backup spring behind the moving half of the clutch. This resulted in better alignment of the clutch, a driving force to move the clutch into engagement once indexing started and ensured that slipping across a tooth could not occur. This simple modification required the purchase of a suitable spring and the manufacture of a collar to locate it on the shaft.
- *Evaluation in the factory:* The additional parts were assembled onto the factory machine and tests run. These worked successfully in all tests and were presented to the client. The Board approved a trial upon a local customer's site.

### *5.3 Epilogue*

- *Risk analysis undertaken successfully:* Before going to the test site a full risk assessment was undertaken and reported back to the Board. This identified the possible modes of failure and indicated that all were now low.
- *Prototype closure arrangement built:* New parts were manufactured.
- *Installed on customer's site:* The least productive machine's on the customer's site was chosen for modification. This was done during the nightshift. Once it was installed and changes explained to the operator he was allowed to continue with production.
- *Evaluation period undertaken:* During the rest of the shift the machine production performance was monitored. No failures occurred. This machine then became one of the most productive on site.
- *Successful conclusion:* Together with the onsite evaluation and comments of the operators were also taken back to the client.
- *Report written and presented to client:* A full report was then written on the design activity and presented to the Board. This was well accepted and the consultant returned home.

## 6 CASE STUDY DISCUSSION

The case study illustrates the structure of the 'theatric' design approach. Here the design problem is seen to be easily broken up into the three segments of prologue core and epilogue. In normal design teaching the effort is concentrated on the core and follows the practice of applying normal techniques. This case study was chosen as it illustrate that the design problem was solved by undertaking two loops of the analysis-evaluation process (the first analysing the design of clutch and the second the analysis of the linkage mechanism). The results of these two investigations provided, in the first instance a conformation that the clutch design had not failed, whilst the second showed the possible true cause. In both cases it was necessary to confirm the outcome of these activities by conducting experimental verification. Whilst this is not often performed during teaching, it can be a vital part of convincing a client that the analysis as correct and to be allowed to move onto the next (and perhaps, more radical) part of the design investigation. The prologue here illustrates that the design investigation (or core) requires a broad understanding of the problem and its 'pre-history' in order to put the design issues into context. The investigation does not start from scratch but builds on the knowledge that has accrued from the previous work. In this case the company had years of experience in building labelling machines especially for the American market. There was also the more recent knowledge of the design they had produced that caused the failure and what they did in their attempts to put is right. These all contributed to the background upon which the main core activities could work and lead to a solution. Similarly the epilogue, unlike most design exercises was used to wrap up the investigation and designed to satisfy the client. Whilst producing a solution was the main aim this also needed to be demonstrated to the satisfaction of the client. This could only really be done through the running of a prototype system in a customer's factory. The remaining activities of assessing the potential risks in the solution and fully reporting what had been conducted on the client's behalf were both contractual issues and good professional practice. Whilst not normally taught as part of design they are key stages in the completion of a design activity.

## 7. CONCLUSION

This paper has presented the design process in theatric context, with the core activity (embodiment and detail) being the ‘play’, the prologue establishing the background and the epilogue which evaluates the success of the design. An industrial case study is presented showing the ‘theatric view as a realistic representation of what transpires in design. The paper also shows that the majority of the design process models taught in modern education miss some of the important factors in the overall process specifically the epilogue. It is the author’s position that the inclusion of these additional aspects of design in the teaching process (prologue and epilogue) would allow the context and core issues of design to be better understood by students.


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