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Identifying differences between novice and experienced designers

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SYNOPSIS

The aerospace industry, along with other industries, has recognised the need to bridge the gap between novice and experienced designers. Research is being undertaken to identify the support a novice designer would require to gain experience faster. A major part of this research is to understand the differences between novice and experienced designers more fully. Results of studies of novice and experienced designers undertaken in the aerospace industry are described. This paper provides the background to the area; describes the data gathering methods; presents the results of the studies; provides some specific examples; and draws conclusions in terms of what actions might be taken to "bridge the experience gap".

1 INTRODUCTION

The long-term aim of this research is to develop a way to support novice designers. In order to understand how to provide this support, it is important to understand *how* novice and experienced designers design. Very little is known about this, as most studies have focused on the time spent on activities, e.g. task clarification and generating concepts (1, Fricke, 1999). Design research has not offered explanations of *how* designers carry out task clarification, or how they generate a concept. Explanations of design have focused primarily on the external activities of designers, rather than focusing on their problem solving process.

Göker examined the effects of experience from repeated exposure to a particular task over a short period of time, and found the activity in the parietal-right region of the brain to increase with experience. This implies that novices use a more deductive approach rather than an

experience-based approach (3). The use of visual information replacing abstract functional models was identified as part of an experience-based approach (3). Gorbert found experienced architects to have better spatial memory; 2-D comprehension (reading plans); and 3-D comprehension (translating plans into buildings) (4).

Christiaans' protocols of industrial design students revealed that more experienced students spent a greater amount of time gathering information and less experienced students considered issues one at a time (5). The less experienced students were found to reason backwards, which is supported in other studies in the domains of physics, medicine and design (6, 7, 8). Waldron *et al* observed that experienced mechanical designers made fewer errors; required fewer references (to the original drawings); and drew longer inbetween references when reproducing mechanical drawings (9).

The current understanding of *how* designers design provides only a limited basis to develop methods to support designers. Current methods of support have focused primarily on expert systems confined to solving a particular problem (10). They rely on storing a large amount of data and inferring from that data to solve problems (11).

2 APPROACH

A full review of the literature has highlighted a need for a greater understanding of the differences between novice and experienced designers. Empirical research based on observations in industry was selected as the most appropriate method for this research. Several research methods adapted from the social sciences were considered. The applied methods were selected based on how well they fulfilled the research objectives and their practicality in an industrial setting. The following research objectives were considered:

- To investigate the differences between novice and experienced designers.
- To understand how novice and experienced designers carry out design activities.

The following issues relating to empirical studies in industry were taken into account:

- The amount of time involved for participants has to be kept at a reasonable level to ensure participation by busy designers.
- The commercial sensitivity of the aerospace industry needs to be respected. The use of video recorders is forbidden and permission needs to be sought for audio recorders.
- Confidentiality of the designers needs to be rigorously maintained.

To address these issues a combination of research methods was used. Two main studies were conducted: 1) observations, and 2) discourse analysis. In addition, interviews were conducted to support the findings from these two studies. Each of the studies gained access to a different part of the design process. The *observations* provided a detailed insight into small slices of the design process; the *discourse analysis* focused upon specific design tasks. The supporting *interviews* provided an overview of the design process. The research methods will be discussed in the following sections, together with the method of analysis used for each study.

2.1 Participants

In total 34 engineering designers from five different teams in an aerospace company participated. Designers with little experience within the company were classed as *'novices'* and those with many years of experience as *'experienced designers'*. Deciding who was

placed in each category was left to the team leaders. It was not assumed that an experienced designer was necessarily a good designer: no attempt was made to assess the quality of a design work. Experience is thought to contribute to being a *good* designer, but once a particular level of experience has been reached other factors become more important (12). By selecting novices with less than two years of experience and experienced designers with over eight years, it is presumed that this level had not been reached.

The average experienced designer had 19.5 years of experience working in the aerospace industry and the average novice designer had 1.5 years. **Table 1** indicates the breakdown of participants for the studies.

Table 1 Participants

	Experienced	Novice
Observations	6	6
Discourses Analysis	8	8
Interviews	6	0
Total Participants	20	14

2.2 Observations

Pure observation provides a limited insight into *how* experienced or novice designers design. For this reason the observations included verbalisation (thinking aloud). Ericsson and Simon found no reliable evidence that structural changes occurred to the cognitive processes if subjects were asked to simply verbalise their thoughts, though they found changes when subjects were asked to explain their thoughts (13 in 7, 14). The researcher did not ask the designers the reason for doing something, as this may have influenced the process. They were only prompted to speak during periods of silence. As the behaviour of designers with varying experience is important for this study, individual designers were observed rather than teams.

The six experienced and six novice designers were observed in their own environment (open plan offices). To keep the environment as real as possible, they were not prevented from asking or answering questions either in person or by telephone. The designers were observed for a period of one-and-a-half to two hours. This did not restrict the amount of time an individual designer spent on the task, but simply the duration of the observation. The designers were not given a specific task, but observed while working on their own design work. The use of a designer's own environment and a real design task has the advantage of being closer to a real-life situation. However, it is less controlled than a laboratory experiment.

Comparison between designers is more difficult than would be the case if they were all working on the same design task. However, the comparison is more valuable as the tasks were not artificial and the conclusions were easier to relate to industry (15). In addition the tasks suited their experience. Carrying out a sufficient number of observations helped overcome the difficulties of comparing designers (16). The observations had little impact on a designer's time, as they simply continued with their own work.

2.3 Discourses

One of the significant findings from the observational study revealed that novice designers are reluctant to approach experienced designers immediately, preferring to save up questions they wish to ask. The discourses consisted of pairs of novice designers interviewing an

experienced designer and therefore provided novice designers with an opportunity to ask experienced designers questions. The focus of the study was to determine the types of questions asked by novice designers; to understand their knowledge needs; and to analyse dialogues between novice and experienced designers.

The term *discourses* has been used to distinguish it from *interviews*. The discourses are treated differently from interviews due to their method of analysis and the absence of the researcher's presence during the discourses. The analysis of discourses focused on the types of queries and the rephrasing of queries by the experienced designers. Analysis of interviews focused on the answers, and hence had to take into account their retrospective nature and any bias of the interviewees. As the discourses were not concerned with interpretation of the actual answers but the types of questions and answers, the retrospective nature was significantly reduced.

In total 11 discourses from part of a knowledge acquisition project set up within the aerospace company were analysed. The twelve-week project was set up to serve two purposes: to increase novice designers' understanding of a particular design process; and to produce web pages for the company intranet describing that design process. The project was a collaboration between the aerospace company and the psychology department of Nottingham University. Transcripts of the discourses were provided for this study. In total 633 queries between the novice designers and the interviewees were analysed. The amount of experience in the aerospace industry of the trainees varied: two of the three pairs had under nine months experience; the third pair had one-and-a-half and eight years experience. The varying levels of experience allowed the types of questions being asked by the different pairs to be compared. The novice designers themselves determined the questions asked during the discourses. The discourses took place in the environment of the interviewee, i.e. the offices of the experienced designers.

2.4 Supporting interviews

All the interviews were with experienced designers. In contrast to the observations, the interviews provided an overview of the design process based upon all previous design projects. The observations provided specific insights into the particular task being observed. The interviews were semi-structured with questions setting the direction

3 RESULTS

All the observations, discourses and interviews were audio-recorded and transcripts generated from the tapes. No categorisation of data was determined prior to analysis. The transcripts from the observations were analysed, a few lines at a time, to summarise the behaviour of the designers and categories were created from the summaries. Categories were generated directly from the queries and answers in the discourses; and from the answers in the interview transcripts. A few additional categories had to be generated in the analysis of later transcripts to accommodate all the data. The final set of categories was then used to reanalyse the earlier transcripts.

3.1 Results from the observations

The observations identified differences between the behaviour of novice and experienced designers. These differences were reported previously (17). Further observations confirmed these results and also provided deeper insights. One of the main findings is that novice

designers were found to use a particular pattern of "trial and error" (also found by (15)). They would generate a decision and then immediately implement that decision. For example, when modifying a compressor blade, the novice designer decided how to modify the blade and then immediately implemented the modification (see **Figure 1**). They then evaluated the implementation and, if unsatisfactory, repeated this process. Novice designers were found to lack confidence in their own decisions, which may explain the need to implement a decision prior to evaluation.

Experienced designers evaluated their decisions prior to implementing them, and thus avoided the trial and error pattern of novices (see **Figure 2**). In the compressor blade example, the experienced designer carefully evaluated the proposed modification *prior* to modifying the blade. The preliminary evaluation stage used by experienced designers is significant in avoiding trial and error. The behaviour experienced designers adopt during this evaluation stage is described in the following sections.

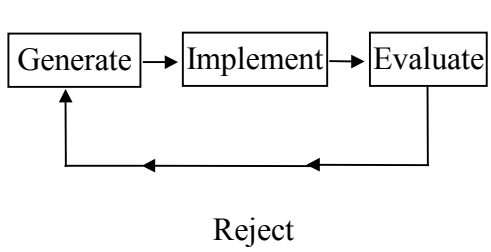

Figure 1 Novice designers' pattern

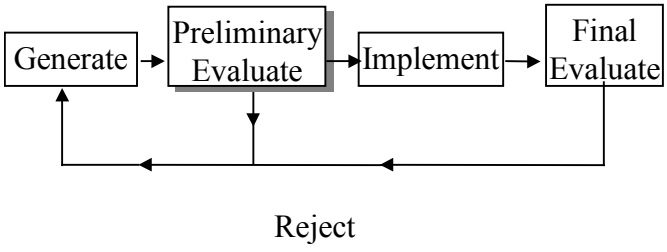

Figure 2 Experienced designers' pattern

3.1.1 Behaviour of experienced designers

Experienced designers carried out a number of activities that novice designers did not. These activities were carried out during the preliminary evaluation stage. The activities and the steps between the activities identified from the observations are shown in **Figure 3**. It is interesting to note that two of the novice designers were occasionally observed carrying out some of these activities. These two were the most experienced of the novices. Their behaviour demonstrated a move towards that of the experienced designers.

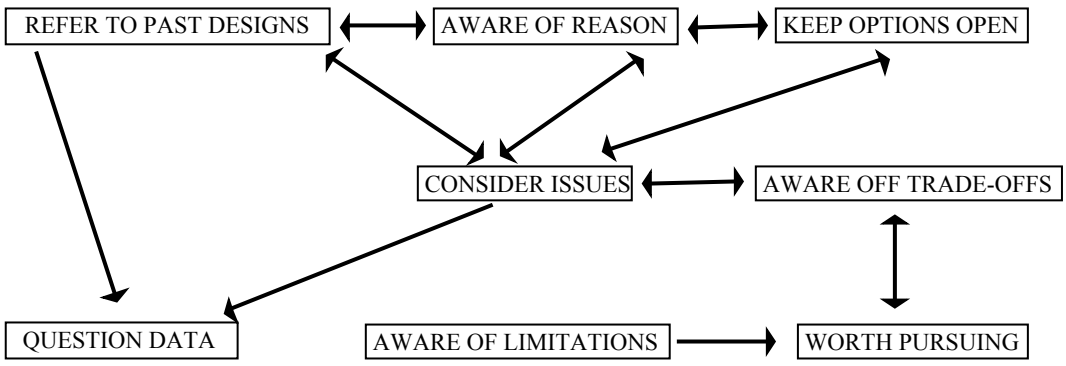

Figure 3 Activities undertaken by experienced designers during the preliminary evaluation stage (see Figure 2) and steps observed between these.

3.1.2 Example

Experienced designers carried out the activities by combining the steps in a variety of sequences, as demonstrated through the following example. During the observations one of the designers received a request from manufacturing to relax tolerances on a locking slot (*consider issues)*. The designer *referred back to past designs* and identified which projects had received similar requests. The designer was *aware of the reason* for the component; the component locked a coupling under high torque and part of the slot was non-functioning. The issue considered was tolerances, and the designer decided tolerances were not important on the non-functioning part of the device (*consider issues)*. The designer also checked the standards for the tolerances and questioned the standard (*question data)*. The standards were written for locking devices with two slots and the current device had six slots. The designer relaxed tolerances for the component and relaxed them even further on the non-functioning part.

The activities categorising the behaviour of experienced designers can be summarised as follows:

- **Refer to past design:** the experienced designers referred to past projects to find similar designs; designs in similar environmental and functional conditions; and where similar problems had been raised and how they were resolved.
- **Aware of reason:** the experienced designers were aware of the reasons behind the use of a particular component (or assembly and feature) or manufacturing process in a particular design. The reasons why a component or process was used may be due to a specific function or the capability of a particular supplier or manufacturing process. In the latter case, knowledge of previous projects may be required. The experienced designers assessed the reasons and their applicability in the current situation. They often referred back to past projects to compare how the component behaved previously. If removing or modifying the component or process would help solve the design problem, this would be carried out.
- **Keep options open:** the experienced designers rejected an option if it limited later options in the design task. They were aware of what needs had to be considered further down the design process.
- **Consider issues:** the experienced designers were aware of relevant issues, and decided which were the most important. They were also aware when issues were not relevant. The issues addressed can be summarised as: 1) product life-cycle, e.g. assembly, maintenance; 2) environmental and functional conditions, e.g. to be used in aircraft with short flights; and 3) product issues, e.g. components, coatings, component interfaces.
- **Aware of trade-offs:** the experienced designers were aware of the relationships between issues. When considering an issue they knew of the effect this issue had on other issues. They were aware that many decisions were based on compromises. Once aware of the trade-off, they would question whether it is worthwhile continuing to pursue the task or implementing a decision (see below).
- **Worth pursuing:** the experienced designers asked themselves how much they could expect to achieve if they continued a particular approach (i.e. if they implemented a decision) and if it was worthwhile.
- **Question data:** the experienced designers questioned data they obtained. This included values given for tolerances, standards, stress models, etc. They questioned the accuracy of the data; how components were modelled or tested; how much accuracy was required; and the applicability of standards.

- **Aware of limitations:** the experienced designers were aware of the limitations of the current design task and hence of the amount of time to spend on it. The following reasons were identified to limit the task: the expected achievement of the current task versus further design tasks; and incompleteness of information e.g. if further changes were required or components required testing.

3.2 Results from the discourse analysis

The questions and answers were categorised along with any additional information expressed. When answering a query, experienced designers often talked about more than one topic and therefore a single answer could fall into more than one category. The following categories emerged from the interviews:

- **Obtaining Information:** the experienced designers were asked explicitly where they could obtain specific information in the form of documents, numerical data, etc. The novice designers required the interviewee to provide details of how to obtain information that was required to carry out the design task. Questions included: Do you get that information from previous engines?
- **Typical Value:** the interviewers requested typical values. These were absolute minimum and maximum values, e.g. What sort of peak power does the high-pressure pump put out?
- **Terminology:** questions were asked to understand what particular terms meant, e.g. What is water hammer? What is suction pressure?
- **Trade-offs:** these questions asked about the effects of one issue on another, e.g. If the pipe diameter in reduced, would that have a negative effect by sucking against a small pipe?
- **How does it work:** these questions asked how a particular part of the engine worked, e.g. Does the fuel go back through the drains? Many of these questions could be answered through domain knowledge, i.e. knowledge of how the engine works, knowledge of manufacturing processes, etc.
- **Why?** these questions tried to establish the reasons why the design is carried out in a particular way, e.g. Is it because fuel flow doesn't take heat from oil? These questions may be answered through *how does it work* or knowledge of specific projects, suppliers, manufacturing capabilities, etc.
- **What issues to consider:** these questions asked what issues should be considered during particular stages of the design process. The questions also asked about the importance of issues, and which issues need not be considered. Typical questions were: Does one of the issues take priority? Does one expect the panels themselves on the intercasing to be excited by vibration?
- **When to consider issues:** these questions asked when issues should be considered, e.g. If it was a centrifugal compressor would it be different?
- **How to calculate:** the novice designers required detail information on how the designer calculates. Example questions included: Would experience tell you that? What specific things do you look for in graphs?
- **Design Process:** these questions asked about aspects of the design process including: the information provided during the design process; what is expected to be produced, etc. A typical question was: When you are approached to come up with a new design, are you given a specification to work to?
- **Company Process:** questions related to how the company works, e.g. Who is your primary customer? What is his job role? Who do you work with?

Each query made by the novice designer (interviewer) was recorded and categorised. Four patterns of query were identified:

- **Pattern 1: Explicit question and answer:** The interviewer asks a question; the interviewee answers the question. The novice designer is aware of what he or she needs to know and which questions to ask. Approximately 33% of the queries fell into this category. This pattern related to the following categories: *obtaining information, how to calculate, terminology*, and *typical values*. Questions were specifically aimed at obtaining this information, as the experienced designers were not observed to offer this information of their own accord. The number of questions on terminology decreased over time, even during the few weeks of the project.
- **Pattern 2: Rephrased or irrelevant question:** The interviewer asks a question; the interviewee rephrases the question or states the question as irrelevant. Approximately 11% of the queries fell into this category. Most of these queries mentioned issues that were not relevant or were due to a misunderstanding of the concept.
- **Pattern 3: Additional information provided:** The interviewer asks a question; the interviewee answers the question and provides additional information. In 18% of the queries, the experienced designers offered additional information to that requested in order to answer a question or respond to a statement. Most of the additional information was *what issues to consider* and *when to consider* them. Experienced designers are aware of what issues need to be considered and when these issues are relevant. This is apparent in the high number of answers received from the experienced designers about what issues are relevant and when to consider issues. The observations also supported this. The more experienced pair of interviewers knew that these questions were relevant and asked a significantly higher number of questions about relevant issues and when these issues were relevant than the less experienced teams.
- **Pattern 4: Statement:** The interviewer expresses a statement; the interviewee provides additional information or declares the statement irrelevant. In 25% of all queries the novice designers expressed statements indicating that they required further information but were unsure of the question.

3.3 Supporting interviews

The interviews confirmed the results from the observations and discourses, namely that experienced designers are able to identify which issues are important. The experienced designers questioned how data are collected and tested. They observed that novice designers tended to calculate numbers too exactly. They were also able to refer back to past projects and use this knowledge when analysing results. Experienced designers were aware of the reason why a component or process is used and have knowledge of how the product (engine) works. In addition to confirming results from the observations and discourses, the interviews suggested that experienced designers had many points of contact, i.e. they knew who to contact; were aware of what reports were relevant; and were aware of what questions to ask to resolve issues.

4 SUPPORT FOR NOVICE DESIGNERS

The results from the studies can be summarised under four headings. When supporting designers the first three headings need to be captured and encouraged. Each heading requires its own approach in order to provide support. The headings are:

- **Questions explicitly asked by novice designers:** Identified in Pattern 1 from the discourse analysis (see section 3.2). Information explicitly requested by novice designers (e.g. terminology, where to obtain information) needs simply to be sought out as the designers are aware of the need to know this.
- **Additional information expressed by experienced designers:** Identified in Patterns 3 & 4 of the discourse analysis (see section 3.2). Additional information expressed by experienced designers (e.g. contacts, what issues to consider) was offered to novice designers in addition to the information they have requested. This implies that novice designers are unaware that they need to know this, hence support for designers needs to make them aware and provide this information without the designers explicitly asking for it.
- **Behaviour of experienced designers:** Identified from the observations (see section 3.1.1). The behaviour adopted by experienced designers needs to be encouraged (e.g. question data, aware of reason). Novice designers need to be made aware tactfully of this type of behaviour.
- **Behaviour of novice designers**: Identified from the observations (see section 3.1). Support for designers needs to encourage a move away from novice designer behaviour (e.g. the use of a trial and error process) towards experienced designer behaviour.

The results imply that support methods that simply help designers search explicitly for information will not be sufficient, as they are rarely aware of all they need to know. A question-based approach could suggest to designers what they need to know, rather than simply providing answers.

The results outlined in this paper are being incorporated into a system to provide support for designers within an aerospace company. This is to be achieved through the following methods: support on the intranet to access information and capture new knowledge; modification of an existing knowledge acquisition project (described earlier, see section 2.3); and a training programme for novice designers. The intranet support is being developed and an evaluation of a 'paper' version is to be undertaken soon.

5 CONCLUSIONS

The results from the studies indicate clear differences between experienced and novice designers, in both their behaviour and their approach to design. The most significant is a preliminary evaluation stage used by experienced designers, which avoids the trial and error process of novices. A tentative explanation of how experienced designers carry out this evaluation stage has been presented. The evaluation stage, together with the other differences identified, has led to a new question-based approach to support novice designers. The results from the discourses revealed that novice designers are not always aware of what they need to know. Supporting novice designers by simply supplying *knowledge* is not enough, they also need to be aware of the general approach. Supplying novice designers with a question-based approach helps inform them of what they do not know.

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