3 NOVICE-EXPERT DESIGN CONSULTATIONS: FINDINGS FROM A FIELD STUDY

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This study investigated the process of novice-expert consultation meetings in an organizational context by identifying phases in the discourse and analysing the nature of these phases. An empirical study was performed at Rolls-Royce Aerospace Engineering. In total 7 audio-records were captured of meetings between trainees (novices) and expert designers that occurred over the course of 3 trainee teams' design projects. 3 main phases, *information seeking, knowledge creation* and *context sharing* were identified and it was found that these phases alternated often. Furthermore, over the course of the trainees' design project the length of the *knowledge creation* phases increased, whereas the length of *information seeking* phases decreased and the length of the *context sharing* phases remained the same. Finally, different roles of experts and novices were identified and suggestions for further research were provided.

Keywords: Design Expertise, knowledge Creation, Discourse Patterns.

1. INTRODUCTION

Acquiring product and process information during the design process is a critical activity, as the quality of the design outcome is dependent on it.[1,2] Empirical studies found that design engineers spend a significant part of their workday searching for information.[3,4] It was shown that the majority of the designers' information needs were satisfied by consulting colleagues rather than by consulting documented forms of information.[4] In addition,[1] found that successful solution searches often occurred while interacting with colleagues and that inter-personal communication is the main means for satisfying designer's information needs.

Research on design expertise showed that experts are better at information gathering and processing than novices[5] due to a number of expert characteristics, which will be described next. Firstly, expert design engineers have by definition more detailed knowledge than novices. Furthermore, they are better at structuring and organizing their knowledge in integrative knowledge structures[6] than novice designers. Because of these integrated structures, experts can, for instance, more effectively focus their solution search effort on the most fruitful areas of the solution space and they can reduce the complexity of the design context to its fundamentals.[7] Finally, expert design engineers are known be able to apply their knowledge in different contexts.[8]

Researchers from different fields agree that it takes up to ten years to become an expert in a particular field.[5,6,9] Considering the time it takes to build design expertise, for industrial companies it is beneficial to accelerate this process. One method to support expertise acquisition is to provide novice design engineers with direct experience of company experts. [10]

Our study focuses on the interaction process of consultation meetings between novices and expert design engineers. In particular, different phases and roles of experts and novices will be identified. The

next section of this paper discusses relevant literature on novice-expert design interactions. Secondly, our empirical study and the findings will be presented. Finally, conclusions and recommendations are provided.

2. NOVICE-EXPERT INTERACTION IN DESIGN

Research into novice-expert interactions is relatively new. The studies of[11] and[12] specifically focussed on novice-expert interactions in design engineering practice.[12] focused on the expert side of the interaction whereas[11] focused on the novice side of the interaction.

Ref. 12 interviewed process experts, team members and other members in the organization, in order to understand the responsibilities of process experts during expert-team interaction, as part of a specific knowledge transfer program in an industrial design engineering company. They found that process experts have seven responsibilities: 1) knowledge sharing; 2) process reference; 3) filling the gaps; 4) process improvement; 5) gaining social acceptance; 6) solution creation; and 7) tool utilization. Although these responsibilities show a particular characteristic of a novice-expert consultation, this study does not actually show how experts interact with novices in order to fulfil their responsibilities.

An investigation that shed light on the interaction between experts and novice designers was the study of.[11] The authors studied novices involved in a knowledge acquisition project in the aerospace industry to understand the novices' knowledge needs. By analyzing the questions and statements that novices posed to experts, it was found that the knowledge needs of novices can be classified into 11 classes: 1) obtaining information; 2) typical value; 3) terminology; 4) trade-offs; 5) how does it work; 6) why; 7) what issues to consider; 8) when issues to consider; 9) how to calculate; 10) design process; and 11) company process. In addition, the answers provided by experts were analysed and classified. The authors found that novice's queries can be classified as questions (71% of the queries) and statements (29% of the queries). Furthermore, novices were found to predominantly query existing bodies of knowledge, which is illustrated by the eleven categories. Since this study was executed in the context of a knowledge acquisition project, this could have influenced the external validity of the study.

This review showed that the current understanding of novice-expert interactions in design is limited. The focus of previous research was either on elements not directly related to the interaction, e.g. experts' responsibilities, or on isolated elements of the interaction, e.g. novices' questions and statements, rather than on the discourse as a whole. Consequently, the results did not describe the process of novice-expert consultations. Furthermore, the context of the novice's design project was neglected in previous studies.

From a methodological perspective, previous research was based on either a retrospective means for data collection,[12] on interviews, or on direct means,[11] used audio-recordings. Furthermore, the experts interviewed by[12] undertook real design projects, whereas the consultations studied by[11] were not related to design projects and therefore the novices might not have been properly motivated.

To overcome the limitations of previous research and to take a more comprehensive view of novice-expert interaction, the researchers decided to undertake an empirical study that met the following criteria:

1. Focus on complete interactions
2. Focus on the entire design process
3. Focus on design tasks in an organizational setting
4. Use direct means of data gathering

3. METHODOLOGICAL APPROACH

A field study was performed in order to capture naturally occurring novice-expert interactions as part of novices' design projects in an organizational setting. The data analysis followed the ethnomethodological perspective,[13,14] which aims to investigate how people socially produce meaning through talk and was previously adopted in design research by for instance[15] and.[16]

The graduate training program at Rolls-Royce Aerospace Engineering, provided an opportunity for data collection. The Design & Make project, which is part of the training program, is a design project in which trainees (novices) work on highly technological projects in groups of four for clients inside the company. During data gathering, the first author followed three trainee teams. As the novice-expert consultation meetings were naturally occurring as part of the trainee's design project, the participants in this research can be considered properly motivated to get the most out of a consultation meeting.

As our aim was to collect meetings across the design project stages,[17] the first author collected consultation meetings during the seven-week 'design phase' of the Design & Make project. For this study seven meetings were analysed, in which different experts were consulted. The main means for capturing the novice-expert consultation meetings was an audio recorder. The gathered audio records were transcribed in order to prepare the data for data analysis.

Since the ethnomethodology paradigm rejects an a priori coding scheme and normative frameworks, a coding scheme was inductively developed from the data.[13] The data analysis was supported by the NVivo software package, a CAQDAS software tool aimed to support qualitative analysis. The final coding scheme characterises the different processes found in novice-expert discourses.

4. RESULTS

This section starts by describing characteristics of the collected meetings. Furthermore, the identified phases, namely *information seeking*, *knowledge creation* and *context sharing* will be defined and examples will be provided. In addition, the distribution of the phases in the different meetings will be presented and the phases' alternation is illustrated. Finally, the meetings will be arranged across the design process stages to investigate how the phase distribution changed over time.

4.1. Data Set Description

Table 1 shows the characteristics of the seven analysed meetings. The meetings are ordered by design process stage,[17] namely the task clarification stage, the conceptual design stage and the detailed design stage. For the purpose of this research *embodiment design* was integrated in the *detailed design* phase. From Table, 1 it can be seen that two meetings took place in the task clarification phase, three in the conceptual design phase and two in the detailed design phase.

4.2. Consultation Phases

The three phases that occurred in the consultation meetings will be defined and illustrated by means of examples from the novice-expert discourse.

1. *Information seeking*
   This phase consists of seeking past product and process information, e.g. design procedures and design rationale. The information seeker employs explicit questioning in order to satisfy the information need, e.g. *"Is there a standard [transport] case you usually buy in for this kind of thing [the measurement device]?"* and *"Do you know why this little thing is here [pointing to a past design]?"* The discourse patterns found in this phase are question-answer sequences.

Table 1. Meeting characteristics.

Meeting	Team	Design stage	Number of words	Duration
1	B	Task clarification	11709	01:07:24
2	A	Task clarification	7698	00:39:30
3	A	Conceptual design	9932	00:54:06
4	B	Conceptual design	8000	00:43:08
5	B	Conceptual design	8539	00:50:06
6	C	Detailed design	3520	00:27:41
7	C	Detailed design	9771	01:01:01

2. *Knowledge creation*
   This phase consists of developing new design knowledge, e.g. generating ideas and analysing solutions. Little questioning is generally employed in the knowledge creation phase. The discourse between experts and novices is often elaborated and rich in arguments, e.g. in the episode presented below, the expert (E1) reasons about the behaviour of the concept as presented by the novices (C and D):

   E1 The difficulty you might face is the mechanism for traversing up and down and across.
   C Yeah.
   E1 Because you're going to have to do that – I don't know; you're going to have to do that using some sort of an electric motor or something.
   D Yeah.
   E1 You can't have the user doing that.
   D No.
   E1 Because it's not going to be consistent enough.
   D Yeah.
   E1 And then your fixture and your device starts to become nightmarishly

3. *Context sharing*
   This phase consists of sharing contextual information, e.g. job title, personal experience, job background and project background. In context sharing, explicit questioning is seldom observed. In contrast, the information is often spontaneously introduced in the conversation. The discourse consists of long conversational turns and therefore is not very interactive. The example presented below illustrates a context sharing phase in which the novice introduces himself, his design problem and his objectives for the meeting.

   M Just to tell you a bit about the background of this. There are four of us working on a Design & Make graduate program. And we've been asked by some engineers from the [department] design a gearbox. Which is like a concept that was invented by someone in [department]. Which is being patented. And in this sort of gearbox, we've got this part [referring to drawing], which is driving a cage which is placed into a laminated element. The aim of this mission is to have a gear ratio of [specific value] between entry and exit. And basically what I'm looking for at this stage is some advice from experienced people regarding bearing design.

Table 2 shows the distribution of the three phases in the seven meetings. The duration of the phases was estimated based on a word count, rather than on the actual time spent in each phase. The assumption here is that the number of words reflects the time spent in a certain phase. A variation of the time spent on the different phases is noticeable and can be explained by the fact that the meetings were captured during different stages of the design process, which we will further elaborate on in section 3.3. Overall, the results show that *information seeking* (8%) only had a marginal role in the meetings compared to the dominant *context sharing* (49%) and *knowledge creation* (43%) phases.

From these findings, it is important to notice how little novices relied on explicit questioning, as is employed in *information seeking* phases, and how much novices relied on satisfying their needs by means of *knowledge creation*, in which expert and novice collaboratively create new knowledge about the design.

Considered that *context sharing* is such a substantial part of novice-expert discourses, this phase is identified as a main supporting process of the *information seeking* and *knowledge creation* phases.

Although the results presented so far may suggest that the consultation phases evolved sequentially, data analysis showed that the phases were fragmented and alternated often.

In order to illustrate this characteristic of the meetings, Figure 1 shows the alternation of the consultation phases for meeting 5. This meeting was organised by team B and took place during the conceptual design stage. A particular example of alternation is presented next.

Table 2. Overview of phases per meeting.

Phase	Meetings							Average %
	1	2	3	4	5	6	7	
Information seeking	19.9%	17.1%	4.4%	3.3%	0.2%	6.4%	1.4%	8%
Knowledge creation	24.4%	38.7%	37.4%	62.1%	52.2%	37.1%	50.9%	43%
Context sharing	55.7%	44.2%	58.1%	34.6%	47.7%	56.5%	47.7%	49%
Total	100%	100%	100%	100%	100%	100%	100%	100%

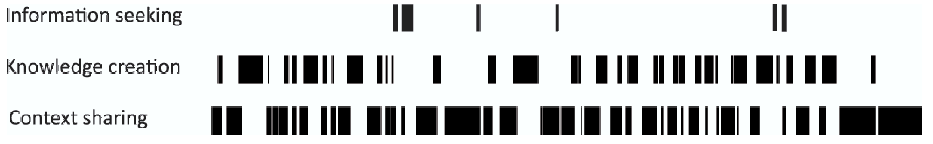

Figure 1. Overview of phase alteration.

Team B worked on a project to develop a new design for a vent pipe restrictor, a feature aimed at controlling the venting of air out of the bearing chamber in a gas turbine. This feature needed redesign because, as a consequence of the undesired venting of oil droplets, oil lacquers can break off from the wall pipes and block the restrictor. A key issue in this project was to design a test rig to evaluate the newly proposed vent restrictor designs. Two segments of the transcript from this meeting, coded with the different consultation phases, are now presented to illustrate the phases' alternation.

[CONTEXT SHARING]

D And our problem is to actually somehow get the sugar solution kind of either nebulised or atomised -
E Yeah.
D And then spray it down as a mist inside the pipe and I guess the finer it is, the easier it's going to — or the quicker to drive but the finer the mist, the smaller the particles, the easier it's going to kind of coat the outside of the tube and actually create some sticky residue there for things to stick to.

[KNOWLEDGE CREATION]

E You used the word solution there.
D Yes.
E And I guess you - we're starting off thinking about oils and liquids.
D Yeah.
E And I was just thinking about could we use a sticky powder; something like you know, seaside rock ground up into flakes like a solid sugar?
D Well,
E That's like — and then dampen -
D ah!
E it slightly.

In the fragment, a member of team B shared with the expert contextual information on a previously generated design option, i.e. using a sugar solution to replicate the oil-air mixture, as well as the subsequent issues that the team faced, i.e. nebulising the sugar solution and spraying it over. The interesting pattern here is that during the conversation the novices shared the nature of their problem and the expert is trying to solve their problem by proposing a solution, namely using a 'sticky powder'. This example shows how the expert contributed to the novices' design project.

In order to gain a deeper understanding of the alternation of phases, the researchers analysed the data to understand who initiated each new phase. Table 3 shows how often either a novice or an expert initiated a new phase. Novices initiated two-thirds of the *context sharing* phases, whereas experts initiated more than 80% of the *knowledge creation* phases. By definition, novices always initiated *information seeking* phases, as these phases reflect the explicit information requests to progress the design task and therefore can only be posed by the novice.

By analysing the phase initiation in more detail, it was found that novices most often initiated *context sharing* phases by expressing a statement, whereas experts often initiated *context sharing* phases by posing a question to the novice. Furthermore, experts initiated the *knowledge creation* phases often by proposing a solution, whereas novices initiated *knowledge creation* phases more often by evaluating the applicability of a previously discussed solution.

4.3. Consultation Phases Along the Design Process

Figure 2 shows the distribution of the three consultation phases across the design process stages. *Information seeking* decreased with the development of the design project. Therefore, the more the product is defined, the less time novices spend on explicitly querying the expert's knowledge. *Knowledge creation* rarely occurred during meetings early on in the design process. It is expected that, at this stage of the design process, the novices do not engage in knowledge creation with the experts because they are still developing their own problem understanding. However, in the conceptual design and detailed design stages, much time is spent on knowledge creation. The time spent on c*ontext sharing* did not change across the design process stages. It is noteworthy that six out of seven meetings were with experts that the novices had not previously met. Only meeting 4 from Table 2, the novices met with an expert they had already previously consulted. It was found that in that meeting, the least time was spent on context sharing.

5. DISCUSSION

The aim of this research was to identify the process of information gathering during novice-expert consultations. Such meetings can be seen as an opportunity for novices to acquire relevant design information and to collaboratively create new knowledge about their design with experts.

Table 3. Overview of phase initiator.

	Context sharing	Knowledge creation	Total
Novice initiated	89	98	187
Expert initiated	31	129	160
Total	120	227	347

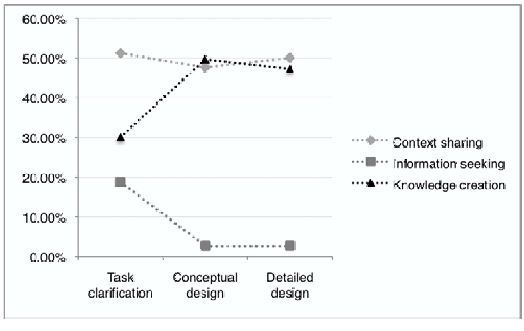

Figure 2. Phases distribution over the design project.

The results showed that in particular *context sharing* and *knowledge creation* phases occurred often during novice-expert consultation meetings. The *information seeking* phases accounted only for a small percentage of the complete meeting. Our findings differ from the findings of,[11] who found that novices posed explicit questions in 71% of their information queries. Furthermore,[11] found that novices most often inquired about existing bodies of knowledge, whereas in our study it was found that *knowledge creation* occurred far more often than *information seeking*. These differences might be explained by the fact that the discourses studied in our research were captured as part of real design projects. Therefore, this research supports the view that it is important to research real design projects.

Furthermore, the findings showed that the phases in the meeting alternated often and that novices often initiated *context sharing* phases whereas experts often initiated knowledge creation phases. Therefore, it appeared to the authors that the expert and the novice had different roles during the consultation. Next, the roles of novices and experts during the three identified phases are shown and reflected upon, see Table 4.

It was found that experts contributed to the novice's design task by providing both design knowledge and design experience. The first is aimed to fill in the information gaps of the novices, as was also identified by [12] and the second is aimed to use the expert's experience as a resource for creating new knowledge about the design. Furthermore, increasing the expert's understanding of a problem is a key task for novices to enable the interaction with an expert. Only by sharing context information, will the information provided and the knowledge created by the expert fit the specific problem faced by the novice.

Based on the different contributions of experts and novices, this study showed the importance of taking into account both the novice's as well as the expert's perspective when studying novice-expert interactions. Therefore, a recommendation for further research is to focus on the *interaction* between novices and experts.

6. CONCLUSIONS AND FURTHER WORK

Concluding, this study showed that the novice-expert interactions could be considered highly complex. However, it also showed that by unravelling phases, roles and characteristics of the discourses, structures and relations appear that can help practitioners by increasing their understanding of elements in the conversation that are of importance to facilitate the consultation meeting. An implication for design managers is to be aware of the importance of stimulating novice-expert interactions as this study illustrated that during these meetings new knowledge about the design can be created, which cannot happen when novices consult documented information sources, e.g. books and company databases.

A limitation of this study was that only seven meetings were analysed, which were captured during aerospace design projects. In order to strengthen the results, further data collection and analysis is

Table 4. Roles of expert and novice designer per phase.

Phase	Information seeking	Knowledge creation	Context sharing
Expert role	Providing information to the novice by responding to explicit information requests, *support the novice's information needs*	Applying the expert's knowledge on the design problem of the novice *to develop the design*	Explaining organizational procedures and job characteristic of the expert *to increase awareness on the novice side of what the novice can expect from the expert*
Novice role	Requesting explicit information from the expert to *fill the information gaps of the novice*.	Implementing explicit information provided by the expert during the conversation on the novice's design problem, to *develop the design*	Explaining the design problem and context to *increase the expert's problem understanding*

required, also by capturing discourses from other design engineering industries. Further research is required to develop a deeper understanding of the specific activities occurring in the different consultation phases and how these activities collaboratively happen. Therefore, the authors will continue investigating novice-expert interactions to address the suggestions for further research as presented above.

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