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Novice–expert consultations as a vehicle for organizational learning: A field study in engineering product development

Fleur Deken, Kristina Lauche, Maaike Kleinsmann,
Delft University of Technology, Department of Product Innovation Management,
Landbergstraat 15, 2628 CE Delft, Delft, The Netherlands
F.Deken@tudelft.nl

Marco Aurisicchio
Imperial College London, Department of Mechanical Engineering,
Exhibition Road, South Kensington, London, SW72AZ, United Kingdom

Rob Bracewell
Cambridge University, Engineering Design Centre,
Trumpington St, Cambridge, CB2 1PZ, United Kingdom

ABSTRACT:

Product development is a knowledge intensive activity and organizational learning across projects and functions is vital for its success. This paper explores novice–expert consultations as a vehicle of social learning through a detailed analysis of meetings during an engineering training programme. Although the meetings were initiated for the purpose of information seeking, this amounted to only 8% of the time compared to knowledge creation between novices and experts (43%) and context sharing (49%). This effect became even stronger during later stages of the project. A correspondence analysis of the conversational balance and activities showed differential patterns for the kind of information provided or requested by both actors, such as novices requesting information on previous designs and organizational procedures while experts inserted unsolicited solutions. Both expert and novice were found to contribute equally and interactively to the discussion and analysis of solutions. The findings illustrate the role of consultations as a means of professional development as well as organizational learning. While it is unlikely that this type of social learning could be replace by a knowledge management system, it could be supported by providing access to members' areas of expertise and by illustrating the rationale of previous designs.

KEYWORDS:

Information seeking, social learning, situated knowledge, professional expertise, apprenticeship

1 Introduction

Developing new products is a knowledge intensive activity. More than other business processes it requires integration of knowledge from different disciplines (Brown & Duguid, 1998). Knowledge is one of the most valuable assets of organizations (e.g. Teece, 1998) and an organization's long-term innovative capability depends on its ability to learn from the past and to integrate diverse knowledge bases. Therefore, it is a vital concern to make full usage of the available knowledge. In order to achieve this, organizations must actively capture, store and transfer knowledge between their members (Mengis & Eppler, 2008): a process commonly referred to as organizational learning.

For new product development (NPD), the need for effective organizational learning practices is amplified by the fast rate of technological change and the high costs of intellectual property rights. Organizational learning is thought to help companies to create better products in a more efficient way (Lynn & Akgün, 2000). Companies also need to learn about external elements during the NPD process, such as their customers and the market, in order to create successful products (Adams, Day, & Dougherty, 1998; Sinkula, 1994; Slater & Narver, 1995). Given the dynamic environments that organizations nowadays operate in, organizations need to adopt a continuous learning approach (Hughes & Chafin, 1996) in which they learn from their past experiences (Duarte & Snyder, 1997; Koners & Goffin, 2007; McKee, 1992; Michael & Palandjian, 2004) and integrate knowledge across different disciplines (Swan, 2003).

However, learning in NPD is not an easy task; learning from experience becomes increasingly harder when the experience of an organization grows (Michael & Palandjian, 2004). NPD has become increasingly more interdisciplinary in nature and NPD teams need to create new products faster (Edmondson & Nembhard, 2009). Cross-community influences are an important means to overcome problems that are unresolved in a specific community of practice (Brown & Duguid, 1998). However, this integration imposes additional challenges of overcoming interpretive barriers between different departments (Dougherty, 1992). We can therefore conclude that knowledge is a barrier as well as an enabler of innovation. Knowledge enables innovation within a function and inhibits innovation across functions. At the boundaries of such functions, problem arise with specialized knowledge (Carlile, 2002). A crucial skill for product developers is therefore to practice their boundary spanning capabilities (Edmondson & Nembhard, 2009).

Detailed empirical studies into the way designers search for information have found that the majority of searches occur via face-to-face interaction (Badke-Schaub & Frankenberger, 1999; Court, 1997; Restrepo, 2004; Wallace & Ahmed, 2003). Despite the advent of knowledge management systems, large amounts of knowledge are not formally documented but 'stored' in people's personal memory (Wallace, Ahmed, & Bracewell, 2005). Therefore inter-personal communication is still a vital means for knowledge sharing and organizational learning (Mengis & Eppler, 2008).

Given this significance of face-to-face interaction in NPD, we are interested in social encounters as mechanisms of organizational learning. We adopt a social learning approach and draw on theories of apprenticeship (Guile & Young, 2001; Lave & Wegner, 1991). Our focus is less on the abstract nature of knowledge and more on how knowledge is situated and enacted in the context of an activity. i.e. *knowing* is a more suitable term than knowledge (Blackler, 1995).

The focus of this paper is on novices in the NPD process and their interactions with senior colleagues. For novices seeking information is even more important, since they have by definition less specialized knowledge to rely upon, compared to more experienced designers. They also know less about the procedures and formal and informal paths of their community of practice. A common way to help novices build up this technical and organizational knowledge is to set up training programs, which bring novices into contact with experts within the company. These programs aim to train junior staff members using the knowledge of their senior staff members in order to facilitate organizational learning (Penual & Cohen, 2003). It is such a training program that forms the setting for the research project presented in this paper. The aim of the study was to investigate how novices and experts collaboratively seek, transfer and create knowledge during consultation meetings. More specifically, relations were identified between 'what' is done 'how' in the interaction.

In the remainder of the paper, we first review the literature on organizational learning and apprenticeship models and then explain the methodology used to analyze novice–expert consultations. The empirical results are presented and discussed in terms of theoretical and practical implications.

2 Conceptualizing organizational learning in NPD

Based on Dewey's (1916) seminal work, many scholars now adopt the perspective of learning as an experiential and social process, rather than the acquisition of knowledge in the abstract. Knowledge transfer and knowledge creation involve much more than transferring the contents of what is in an individual's head or in a particular database to another person's head via a book, lecture, or e-mail (Nonaka 1998). While Dewey's concept of learning was aimed at the individual, his ideas have been adapted from the cognitive level of the individual to that of the organization (Easterby-Smith & Lyles, 2003; Elkjaer, 2003). This means that knowledge, and particularly 'knowing how', is a social product of the accumulated experience of a communities work practice (Brown & Duguid, 1998; Cook & Brown, 1999; Lave & Wegner, 1991). These practice-based approaches have emphasized that knowledge is embedded in what a community does and needs specific mechanisms such as boundary objects, to be communicated across communities (Leigh Star & Griemser, 1989). Only by understanding the circumstances and how the participants construct the situation, a valid interpretation of a learning activity can be made (Gherardi, Nicolini, & Odella, 1998).

For the context of New Product Development, generative learning is of specific interest, in other words how new knowledge is created (Miner & Mezias, 1996). Theoretical conceptualizations and empirical studies of knowledge sharing in NPD point to the dynamic and interactive nature of knowledge creation. Problem spaces and solutions are constructed dynamically, through interactions between different people (Brown & Duguid, 1991). Blackler (1995) describes communication-intensive organizations as the ones most capable of innovation, as their emphasis is on the collective endeavor and creation of new knowledge while focusing on solving 'new' problems rather than on 'similar' ones. Communication-intensive organizations should be better prepared for innovation than expert-dependent, knowledge-routinized organizations, or symbolic-analyst dependent organizations. As knowledge is susceptible to transformation, the source for new knowledge lies in the use of knowledge as a tool for knowing within a situated interaction with the social and physical world (Cook & Brown, 1999).

Based on an ethnographic study in a production company as part of an NPD process, Bechky (2003) found that a systematic approach for knowledge sharing in an organization may not be the solution to communicate local knowledge across boundaries. Rather, she argues that organizations should stimulate interactions between different communities of practice alongside the formal processes in order to increase the understanding between the different disciplines. Co-creating common ground between members of different communities includes a transformation of how they perceive the design problem at hand. These direct interactions made boundary spanning and knowledge transfer successful.

These findings also have implication on how newcomers should be introduced in their destined community of practice. Knowledge transfer and learning between novices and experts is most effective when focused on actual problems (Penual & Cohen, 2003). Similarly, Bechky (2003) suggests that newcomers should be introduced by means of activities that can facilitate the creation of shared understandings as present in these communities by for instance storytelling and apprenticeships.

The concept of apprenticeship learning received some renewed attention in the light of the current perspective of leaning as being social and situated (Lave & Wegner, 1991). Guile and Young (2001) proposed apprenticeship learning as a conceptual basis for the social theory of learning building on Lave and Wegner (1991) and Orr (Orr, 1990). During an apprenticeship, the apprentice participates in the community of practice and is socialized into the community (Beyer & Hannah, 2002). Blackler (1995) also identified apprenticeship learning as a means to transfer tacit knowledge, existing within a community of practice, to apprentices or organizational newcomers.

In line with social learning approaches, the content of learning is not to know about practices, but to become a practitioner (Elkjaer, 2003). The socialization of new organizational members means developing a social identity in order to function effectively in the new organization (Beyer & Hannah, 2002). Newcomers acquire knowledge, internalize and practice new processes and make sense of their new experiences in line with their past experiences. They need to actively seek information to reduce uncertainty during their organizational entry process (Miller & Jablin, 1991). They can rely on official messages, direct colleagues and other contacts within the organization, or external sources. Cross and Sproull (2004) found that people most often referred to other people when seeking for actionable knowledge, i.e. knowledge that can lead to immediate progress on the task one works on. They identified five components of actionable knowledge: providing *solutions* for the information seeker's problem, *referrals* to other information sources, a *problem reformulation*, *validation* of proposed solutions, *legitimating* with influential people to speed up their projects by securing agreement of the organization or clients. However, there is only limited empirical research on the relation between the content of information sought and how the newcomers seeks information, and Cross and Sproull (2004) ask for a detailed investigation of actual information seeking interactions.

2.1 The present study

This study aims to address this gap by analyzing novice–expert consultations on the micro-level of verbal communication. In line with Barley and Kunda's (2001) argument for more detailed studies of work to advance organization theories, the study was conducted in a field setting of a trainee programme. Our approach follows Blackler's (1995) call for detailed and ethnographic studies to shed light on *how* people improvise, communicate and negotiate. Conversations were chosen as they are the most important means for enabling knowledge sharing and knowledge creation in organizations (von Krogh, Ichijo, & Nonaka, 2000). In line with the conceptualization of Mengis and Eppler (2008), conversations are seen as face-to-face interactions within a small group of co-located people, interacting through verbal and non-verbal means. They provide an angle into organizational discourse and into micro routines, as Jarzabkowski and Seidl (2008) showed for strategy meetings. This is particularly true for creative processes in NPD: as language is not only used to report and describe but also to create with (Boje, Oswick, & Ford, 2004), and conversations are a means for studying design activity (Heritage, 2001).

The aim in the present study was not to take a prescriptive viewpoint regarding desired behaviors of people involved in conversations. Rather, we aim to shed light on the micro-processes that occurred in meetings in order to increase our understanding of the functioning of such interactions as a means for organizational learning (Barry & Crant, 2000). The research approach is depicted in Figure 1: Novice–expert consultations are seen as a social process (Nonaka & Konno, 1998) and are therefore studied from the novice's as well as the expert's perspective. The driving force behind the consultations is the novice's knowledge need (Ahmed & Wallace, 2004b), as this is ultimately the cause for the interaction to occur.

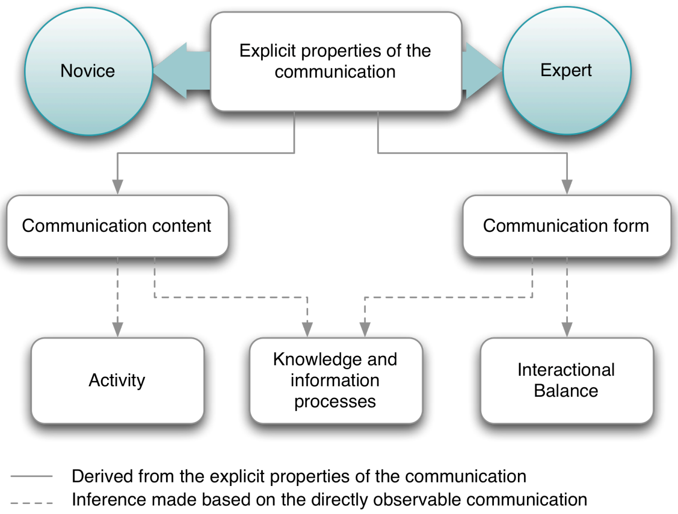

Figure 1 Analysis of novice–expert interactions in terms of content and form

As is common for this kind of studies, the explicit verbal communication occurring during novice–expert interactions was taken as a point of departure (e.g. Luck & McDonnell, 2006; Heritage, 2001). The interaction was then further analyzed in terms of (1) the *content* of the communication and (2) the *form* of the communication, addressing *'what'* is uttered *'how'* respectively (Ahmed & Wallace, 2004a; Hmelo-Silver & Barrows, 2008; Hogan, Nastasi, & Pressley, 1999). Following the first route, an inference about the *type of activity* that the novice and expert are performing (see the dotted lines on the left in Figure 1) can be made based on the communication content. This is in line with the tradition of protocol analysis in design research (e.g. Badke-Schaub (Badke-Schaub & Frankenberger, 1999; Cross, Christiaans, & Dorst, 1996; Valkenburg & Dorst, 1998). The second route addresses (see the dotted lines on the right in Figure 1) the roles of novices and experts in the conversation and *how* a message is phrased, i.e. as a question or statement (Ahmed & Wallace, 2004a; Hmelo-Silver & Barrows, 2008). Based on the analysis regarding the activities and conversational balances, the main knowledge and information processes (K&I) that occurred during the meeting were identified.

Based on these three routes of inquiry, we aim to answer the research question of *what* is done *how* in novice–expert consultations: which roles do novice and expert play, and how do they share and co-create knowledge during these conversations?

3 Method

The research approach consisted in undertaking a field study in order to collect consultations between novices and experts as part of the novice's design project. The oral communication that occurred during the face-to-face meetings was captured and the verbal transcripts of the meetings were analyzed. Communication other than what is expressed explicitly via the *verbal communication channel* was not taken into account in this research, i.e. communication via the paralinguistic and non-verbal communication channel. In addition, it was not intended to assess whether or not the receiver correctly understood the transferred messages.

3.1 Sample

The research setting was the graduate training program at Rolls-Royce Aerospace Engineering. The first author observed meetings that occurred as part of the trainees' Design & Make project. During the Design & Make project, trainees worked on highly technological projects in groups of four, for different customers inside the company. The trainees completed two previous placements in Rolls-Royce that were not design related; therefore the trainees are considered novice designers. Furthermore, since the novice–expert consultation meetings were naturally occurring over the course of the trainees' design projects, the participants in this research can be considered properly motivated to get the most out of a consultation.

During data gathering, the first author audio-recorded the communication during novice–expert consultation meetings, which were converted into transcripts. As shown in our conceptual model of novice–expert interactions, this research focused on the explicit properties of the communication. Therefore, the objective of the transcription was to compose a complete record of what was said during the consultation. For the purpose of this research, seven meetings of three different teams were analyzed, distributed over the novice's design process, as is shown in Table 1. It was aimed to acquire a data set of meetings distributed over the different project stages – task clarification, conceptual design and detailed design – and the three different design teams.

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

3.2 Data analysis

The verbal transcripts were analyzed on different grain sizes (Hmelo-Silver & Barrows, 2008). The main knowledge and information (K&I) processes – the largest grain size – that occurred during the meetings were captured by means of the first coding scheme. The second and third coding scheme, one for the *activities* performed during the meetings and one to characterize the *conversational balance*, were deductively developed to operationalize the conceptual model as was shown in Figure 1. The activity and conversational balance coding schemes are grounded in literature but were inductively adjusted to better fit the data (Miles & Huberman, 1994). The activity coding scheme aimed to capture the different activities that occurred in the novice–expert interactions and the second coding scheme aimed to characterize the *conversational balance* during the consultation meeting. The number of words coded in a certain coding category was used as a measure for determining how often a certain activity or conversational balance code occurred as percentage of the entire consultation.

3.2.1 Knowledge and Information process codes

The first coding scheme, the *knowledge and information processes* contained three codes: (1) *information seeking*, (2) *knowledge creation*, (3) *contextual information sharing*. The *information seeking* process enclosed all explicit information requests, or questions, posed by novices and the corresponding expert reply. When novices and experts got involved in highly interactive discussions in which new knowledge was created regarding the novices' design task, this was defined as a *knowledge creation* process. Finally, when the novice and expert were explaining contextual information, e.g. their educational backgrounds, or the history of the design task at hand, this was identified as *contextual information sharing*.

The *information seeking* process 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]?"*. In Dewey's terminology, the novice's behavior can be described as a productive inquiry: a deliberate attempt to seeking what one needs in order to do what one wants to do (Cook & Brown, 1999).

The *knowledge creation* process consists of developing new design knowledge, e.g. generating ideas and analyzing solutions. Little questioning is generally employed in the knowledge creation phase.

Contextual information sharing refers to providing background to the problem at hand. In Cross and Sproull's (2004) study respondents indicated that when a problem was not fully specified, which occurred most often, they had to first lay out the various dimensions of the problem before they could generate solutions.

3.2.2 Activity codes

The second coding scheme, the *activity codes*, captured the activities that occurred during the consultations, e.g. explaining past design solutions or generating design solutions. The third coding scheme, the *conversational balance* scheme, captured the initiator and the provider of the information in the interactions between expert and novice, as was explained in the conceptual model in Figure 1. The units of analysis for both the *activity* as well as the *conversational balance* coding scheme, are series of utterances. An utterance is defined as a unit of speech bounded by the speaker's silence or interruption by another speaker (Hmelo-Silver & Barrows, 2008).

The *activity coding* scheme is build upon the unit of analysis of series of utterances *in which the same activity occurred*. Often these series included several utterances. The initial version of the activity coding scheme was based on the coding scheme of Stempfle and Badke-Schaub (2002), which described problem-solving activities, such as problem understanding and solution generation. Through interaction with the data, task-related activities, e.g. sharing information about organizational procedures, were inductively added to the coding scheme. The final list of codes and a description per code categories is shown in Table 2.

Table 2 Activity codes

Category	*Description*
1. Problem understanding (PU)	Discussing the design problem, its background, the causes of the problem, implications of the problem and the problem context of the novices' *current design project.*
2. Requirement finding (RF)	Defining, adjusting, adding or sharing the requirements of the *current design task.*
3. Past design discussion (PD)	Discussing a past design solution for both the current problem as well as other solutions.
4. Solution explanation (SE)	Explaining potential solutions for the current design project, generated before the consultation.
5. Solution generation (SG)	Generation of new (sub-) solutions for the current design project.
6. Solution analysis (SA)	Predicting of behavior, discussing judgments, or evaluating of (sub-) solutions.
7. Decision making (DM)	Deciding regarding the design or design process.
8. Design process (DP)	Discussing the process of the current design project.
9. Communication process (CP)	Meta-communication, introducing people, discussing meeting objectives.
10. Organizational information sharing (OI)	Discussing company procedures, information sources, or expertise distribution in the company
11. Team coordination (TC)	Discussing the current and or future collaboration between the expert and novice(s)

3.2.3 Conversational balance codes

In order to characterize the information flow in the interactions, a distinction between *information pushes* and *information pulls* is made. This terminology is adapted from information technology research, e.g. Cybenko and Brewington (1999) where it is used to describe operations for addressing information resources. For the *conversational balance* coding scheme, the unit of analysis is a series of utterances bounded by changes in the topic under discussion (Brown & Yule, 1983). Utterances were first classified as either *statements* or *questions* (Ahmed & Wallace, 2004a; Hmelo-Silver & Barrows, 2008).

Sequences of statements are further defined as *information pushes*, which can be initiated either by the novice or by the expert, resulting in a *novice push* and an *expert push* respectively. Furthermore, a question posed by either the novice or the expert and the corresponding answer is identified as either a *novice pull* or an *expert pull* respectively. In this manner, by identifying sequences of utterances in a conversation, the *conversational balance* can be determined. The initiator of an information push or pull is perceived to be the person who steers that particular part of the interaction.

Observations regarding topic changes showed that in sometimes a question was posed but answered at a later time in the meeting without the question being restated, e.g. after a previous issue was resolved. It was decided to code the posed question as an information pull and the corresponding, yet delayed, answer as a *delayed answer*.

During data analysis, the first author found that the codes did not cover all possible combinations of information provider and initiator; some series of utterances on the same topic consisted of statements of both parties, e.g. associative thinking discussion during idea generation. Due to the interactive nature of such fragments, it was decided to add an interactive code to the conversational balance coding scheme. An overview of the different conversational balance code categories is shows in Table 3.

Table 3 Conversational balance codes

Categories	*Description*
Expert push	Expert initiated sequence of statements in which the expert is the information provider
Expert pull	Expert initiated sequence resulting from a question, in which the novice is the information provider
Novice push	Novice initiated sequence of statements in which the novice is the information provider
Novice pull	Novice initiated sequence resulting from a question, in which the novice is the information provider
Expert delayed answer	Expert answer to a question earlier in the consultation asked by the novice
Novice delayed answer	Novice answer to a question earlier in the consultation asked by the expert
Interactive	Iterative expert and novice statements

The data was coded using NVivo, a software tool that supports coding documents as part of qualitative analysis (Lewins & Silver, 2007). Both qualitative and quantitative analysis methods were used to further analyze and make sense of the codes' frequencies and the occurring code patterns. The analysis of the codes was performed by means of querying code frequencies in NVivo, which was captured in frequency tables.

4 Results

4.1 Results knowledge & information processes

The three different knowledge and information processes, namely information seeking, knowledge creation and sharing contextual information will be discussed below. First, the time spent on each of the processes per meeting and an indication of the iteration between the processes within meetings. Finally, the time spent on the processes over the course of the design project is shown.

Table 4 shows the distribution of the three *knowledge and information processes* 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. Overall, the results show that *information seeking* (on average 8%) only had a marginal role in the meetings compared to the dominant *context sharing* (49%) and *knowledge creation* (on average 43%) phases and *contextual information sharing* (on average 49%) 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 *contextual information 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.

Table 4 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%

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 2 shows the alternation of the phases for meeting 5. This meeting was organized by team B and took place during the conceptual design stage. A particular example of alternation is presented next.

Figure 2 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.

4.1.1 Knowledge and information processes along the design process

Table 1 shows the distribution of the three consultation phases across the design process stages. *Information seeking* decreased with the development of the design project ($r = -.929$, $p < .01$). Therefore, the more the product is defined, the less time novices spend on explicitly querying the expert's knowledge. A significant positive correlation was found between the time spent on knowledge creation and the design stages time scale ($r = 857$, $p < .05$). *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 problem understanding. However, in the conceptual design and detailed design stages, much time is spent on *knowledge creation*. The time spent on *contextual information 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, see Table 1, the novices met with an expert they had already previously consulted. As can be seen, in that meeting the least time was spent on sharing contextual information.

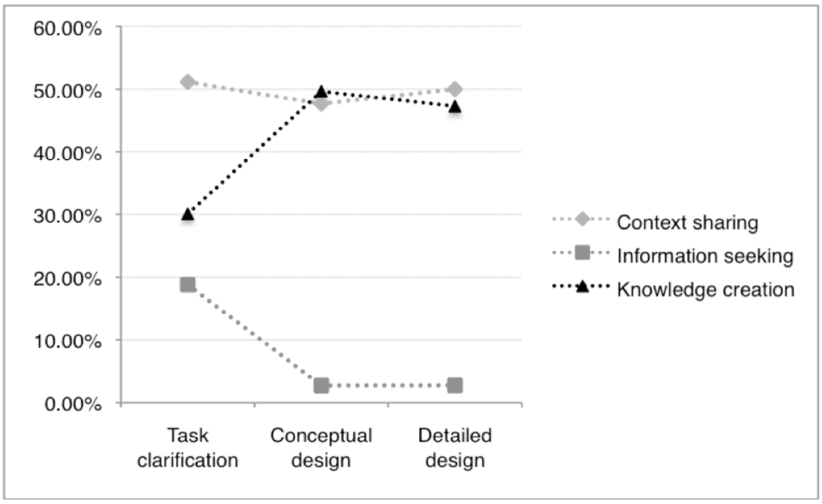

Figure 3 Phases distribution over the design project

4.2 Conversational balance and Activity codes

In this section, first examples of the different coding scheme categories are provided for the Activity and the Conversational balance scheme. Furthermore, the co-occurrence frequency table of the two coding schemes is shown. Finally, the correspondence analysis sheds light on the relations between the two coding schemes.

In order to further illustrate the nature of the conversational balance codes, examples of the codes applied on a fragment of one of the transcripts is provided in Table 5.

Table 5. Example Conversational balance codes

[Novice push]	
M	This is just like a preliminary concept sort of thing. This is sort of like a feeder for the particulate that we're adding, like the flaky mixture. Into a cylinder which would be at 2 bars either side.
D	About that, yes.
M	And then we've got like fluid or adhesive sticky mixture being pumped in through a spray nozzle, so it sort of can coat the particles as it mixes and then sort of comes down her to a vent restrictor which can be interchangeable, and then caught in some sort of drum with like a mesh or a sponge on top to sort of filter out the particulate. But we're having issues with how we're going to actually feed the particles at a constant rate and how we're going to actually spray – get a nozzle that will create a fine enough mist that it won't just hit the outsides and run down as a drip.
E	Ok
M	We were thinking possibly we could use like some sort of a beaker with fluid in and use one of these ultrasonic units.
[Expert push]	
E	That’s a bit out of my range here.
[Novice push]	
M	It's basically like a little plate that vibrates at ultrasonic speed, isn’t it. And sort of –
[Expert pull]	
E	Shakes it off?
M	Yeah, it atomises liquids. It's like when you get these cauldrons and you have mists overflowing the side, that sort of thing.
E	Ok yeah

M So you get a very fine mist flowing round here. And then with there being air coming into here anyway, it drags the mist along with it.
E And entrain it through, yeah.
[Novice push]
M But basically we're looking to see if you had any ideas of – or if you've been anything before, how you can introduce particles into a flow.
[Expert push]
E The last group I was working with on – last graduate group, were introducing a – by firing sand and dust into – and they used – I don't know whether it's a similar sort of thing, but they used like a worm screw.
M Ok
D Right
E And it'd be in line with a hole and then it just dropped it through a chute into –
M Ok
E because they were trying to put very fine sand into it. It was pipe clips round a pipe for the JSF. And they were trying to make sure none of these particles got underneath the clamps when they were clamped up. Because obviously if they get underneath them then they get vibration, you get fretting. So they had to introduce these very fine particles at so many – at a set rate and then blow it through.
[Novice pull]
D Was that a metered quantity they were putting in rather than just –
M Yeah, the other problem we've got with that is that this is sort of slightly pressurised, isn't it? So having screw feed going into that, it'd have to be sort of sealed and –
D Yeah, you'd need some form of positive displacement.

Additionally, the frequencies of the occurrence of all possible code combination on the *activity* and *conversational balance* categories were queried. As the coding schemes were independently developed, applied and were based on different units of analysis, the codes often started at different points in the transcripts. Hence, simply counting the co-occurrences of utterances between the two coding schemes was not an option. It was, therefore, decided to count the number of words coded with every combination of the two coding scheme categories as a frequency measure. The co-occurrence of the coding categories was further analyzed by means of a correspondence analysis, in which the structure between the two coding schemes was visually represented (Hair, Black, Babin, Anderson, & Tatham, 2005).

An overview of the time spent on the different activity and conversational balance categories is shown in Table 6. As was stated in the method section, a word frequency measure was used to estimate the time spend on each of the different code categories. The rows in Table 6 show the various activity code categories and the columns show the conversational balance code categories.

On average, from the different identified activities, most time was spent on solution analysis (29.9%), problem understanding (15.1%) and solution explanation (10.2%). In total 75% of the time was spent by the experts and novices on problem-solving activities, the sum of the first seven activity codes, see Table 2.

Furthermore, Table 6 shows that on average expert pushes occurred most often (43.2%), followed by novice push (18.8%). Therefore, these results illustrate that the expert is most dominant in the conversation, by pushing information and identifying new discussion topics.

When analyzing Table 6, it can be seen that certain activities seem more related to specific conversational balance code categories. For example, the activity past design discussion occurs most often in combination with an expert push. Based on this observation, the relation between the two coding schemes was further analyzed.

To investigate the relations between the two coding schemes in order to arrive at findings regarding 'what' is done 'how' in novice–expert consultation meetings, a correspondence analysis was performed. Correspondence analysis is a multivariate method for the explorative investigation of underlying structures in cross-tabular data (Greenacre, 1994; Hair et al., 2005). The explorative nature of this statistical technique fits well with the objective of this study, as no predetermined hypotheses were defined.

Table 6 Coding frequencies and co-occurrence

Activity	*Conversational balance*								
	Expert push	*Expert pull*	*Novice answer (delayed)*	*Novice push*	*Novice pull*	*Expert answer (delayed)*	*Interactive*	*Total*	*% of total*
1. Problem understanding	3342	1153	38	2696	1291	462	99	9081	**15.1%**
2. Requirement finding	397	380	0	746	93	110	311	2037	3.4%
3. Past design discussion	4478	31	0	163	710	112	0	5494	9.1%
4. Solution explanation	615	2377	134	2647	35	0	0	5808	10.2%
5. Solution generation	3598	41	50	93	360	0	510	4652	7.7%
6. Solution analysis	6225	1206	0	2246	938	181	7148	17944	**29.9%**
7. Decision making	74	0	0	10	23	8	0	115	0.2%
8. Design process	3050	309	0	2195	532	130	607	6823	11.4%
9. Communication process	803	394	0	370	30	0	37	1634	2.7%
10. Organizational information	2318	28	0	143	1569	0	127	4185	7.0%
11.Team coordination	1047	175	0	0	665	0	386	2273	3.8%
Total	25947	6094	222	11309	6246	1003	9225	60046	
% of total	**43.2%**	10.1%	0.4%	**18.8%**	10.4%	1.7%	15.4%		100%

As Figure 4 shows, a single map was composed in which the association between the categories of the non-metric variables – here the two coding schemes – is presented. The associations between the two coding scheme categories are based on the chi2 statistic. The correspondence map shown in Figure 4, distinguishes two dimensions on which the association between the categories is based upon (Hair et al., 2005).

Together the two dimensions explained 83.1% of the inertia. The term 'explained inertia' has a similar meaning as the term 'explained variance' in a regression analysis (Greenacre, 1994). Adding a third dimension only added a marginal contribution to the total explained inertia and therefore a model with two dimensions was selected.

Results from the correspondence map will be derived in two ways: by means of interpreting the dimensions of the map, and by assessing the associations among categories. In order to make sense of the map, meaningful names will be inferred for the two dimensions. This inference process can be compared with naming factors in explorative factor analysis or in principal component analysis. As the dimensions represent relative distances between the code categories per separate scheme, inferring from the graph, see Figure 4, can only be done by analyzing the coordinates and contributions of the categories per separate coding scheme, as shown in Table 7.

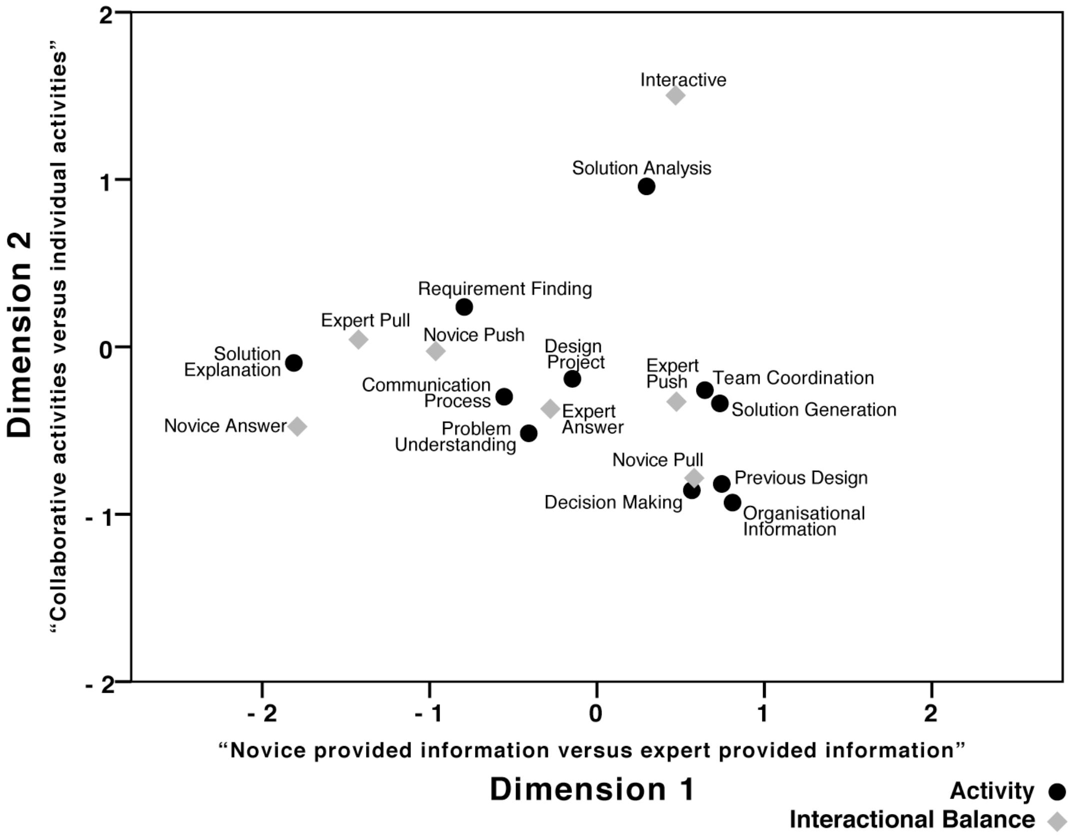

Figure 4 Correspondence map

The first dimensions explained 49.4% of the total inertia. Of the activity codes, the category solution explanation had both a highly negative coordinate and accounted for 57.1% of the entire explanatory value of the inertia, as can be seen in Table 7. Additionally, the categories requirement finding and problem understanding were found on the negative side of dimension 1, accounting for 3.8% and 4.5% respectively of the total explained inertia by dimension 1. To a lesser extent, the past design discussion and the organizational information explanation accounted for 9.2% and 9.3% respectively of the explained inertia by dimension 1. Therefore, it appears that dimension 1 ranges from information about the novices' project to information about past design experience and organizational information.

The conversational balance categories found on the negative side of Figure 4 were novice answer, expert pull and novice push. These categories had the highest negative coordinates, as can be seen in the coordinates column in Table 7.

The categories novice pull, expert push and interactive were found on the positive side of Figure 4. The expert answer category had a coordinate close to zero. In the contributions column of Table 7, it can be seen which categories of the two coding schemes impacted the orientation of the dimension most; the expert pull and novice push categories accounted for 36.7% and 31.3% of explained inertia by dimension 1 respectively. Based on these results, it is inferred that dimension 1 ranges from novice proved information to expert provided information, which is shown in Figure 4.

When the two interpretations of dimension 1 are combined, it was inferred that during the meeting, the novice contributed information related to their project, by means of explaining their design problem, potential design solutions and by sharing their requirements. Furthermore, the expert contributed by sharing information based on their design experience and their organizational knowledge.

Table 7 Coordinates and contributions of dimensions

Code	*Coordinates*		*Contributions*	
	Dimension			
	1	2	1	2
Problem Understanding	-0.408	-0.516	0.045	0.088
Requirement Finding	-0.793	0.238	0.038	0.004
Past design	0.745	-0.819	0.092	0.134
Solution Explanation	-1.811	-0.096	0.571	0.002
Solution Generation	0.734	-0.338	0.075	0.019
Solution Analysis	0.296	0.959	0.047	0.599
Decision Making	0.567	-0.857	0.001	0.003
Design Project	-0.147	-0.191	0.004	0.009
Com. Process	-0.555	-0.298	0.015	0.005
Org. Information	0.81	-0.93	0.082	0.131
Team Coordination	0.645	-0.259	0.028	0.006
Expert Push	0.467	-0.329	0.17	0.102
Expert Pull	-1.416	0.049	0.367	0.001
Novice Answer	-1.796	-0.485	0.021	0.002
Novice Push	-0.961	-0.029	0.313	0
Novice Pull	0.584	-0.772	0.064	0.135
Expert Answer	-0.275	-0.353	0.002	0.005
Interactive	0.478	1.502	0.063	0.755

The second dimension explained 33.7% of the total inertia. Regarding the activity categories, on the positive side of dimension 2, solution analysis accounted for 59.9% of the total explained inertia by dimension 2. On the negative axis, many categories were found, which only accounted for a small amount of the total explained inertia by dimension 2. The categories from the extreme of the negative axis towards zero were: organizational information explanation, accounting for 13.1% of the explained inertia, decision making, accounting for 3% of the explained inertia, past design discussion, accounting for 13.4% of the explained inertia, and problem understanding, accounting for 8.8% of the explained inertia. The other categories' coordinates were located closely to zero.

Of the conversational balance categories, on the positive axis interactive was found at the right most position, which accounted for 75.5% of the inertia explained by dimension 2. Furthermore, the novice pull category represented the far most end of the negative side of dimension 2, by accounting for 13.5% of the explained inertia by dimension 2. To a lesser extent, the negative axis of dimension 2 was represented by the expert push category, which accounted for 10.2% of the inertia explained by dimension 2. Therefore, it appears that dimension 2 ranges from collaborative to individual contributions.

An interpretation of dimension 2 is that clusters of activities are more likely to co-occur with either the collaborative interaction category interactive versus the individual categories of conversational balance. The activity solution analysis was closer related the interactive conversational balance, whereas the activities organizational information explanation, past design discussion and problem understanding, were closer related to other, individual conversational balances, mostly represented by novice pull. Therefore, this dimension seemed to describe activities that occurred collaboratively versus individually

5 Discussion

The aim of this study was to explore novice–expert interactions as a vehicle for organizational learning. Knowledge and information processes, activities and conversational balances were analyzed on a fine grain-size.

It was found that the three main phases that occurred during such consultation were: context sharing, knowledge creation and information seeking. Furthermore, it was found that during the different phases, the novice and expert had different contributions: during *information seeking*, the novice posed questions to the expert who tried to answer these questions in return. During *knowledge creation*, the novice generated new knowledge by applying the information found during information seeking phases on their design task; the expert applied his experiential knowledge on the novice's design task in order to generated new knowledge about the design. Finally, during *contextual information sharing*, the novice shared information about their design task with the expert and the expert shared information with the novice about their field of expertise and how they operated in the organizational setting.

This study found that different activities were initiated and steered differently during the interaction. Solution analysis efforts were executed collaboratively – by means of a highly interactive discourse – whereas the expert and novice executed activities, such as solution explanation and organizational information sharing, individually. The novice provided the information during solution explanation and to a lesser extent during requirement finding. The expert provided the information during activities such as organizational information sharing, design process and past design discussions.

Experts were found to contribute information that is not likely to be documented in the organization, e.g. experts explained novices how to find information in their informal network, or explained alternative solutions that were considered in projects they were previously involved in. For novices having access to these types of information can be valuable and speed up their design project.

These findings indicate that it is not only the expert who transfers knowledge during the consultation. Rather than observing novices inquiring an expert, it was found that novices had specific pieces of information that were shared with the expert: explaining the solution they consider, sharing design requirements and explaining the design task at hand. Sharing such information enables experts to select the fragments of knowledge that will be useful for the novice.

Therefore, this study indicates that consultation meetings are a true two-way interaction, as was conceptualized, and that the success of such a consultation is dependent on the information shared by both the expert and the novice.

Furthermore, rather than finding experts being queried by novices, experts and novices were found to get involved in deep discussions in which solutions were generated, evaluated and decided upon. Therefore, during consultations actual collaborative design instances were found to occur. This dearth of explicit questions during consultation meetings between novices and experts was also found by Ahmed and Wallace (2004a). Yet as their study was performed in the context of a knowledge acquisition project and unrelated to actual design efforts of novices, they found no indication of collaborative design. Therefore, this study underlines the importance of investigating design communication related to real projects.

Furthermore, our research team did not expect that approximately half of the consultation meeting would be spent on contextual information sharing, as this process only supports the information seeking and knowledge creation processes. Therefore, it appears that during novice–expert interactions much must be shared between the speakers before they can focus on the actual sharing and creation of knowledge. Hinds and Pfeffer (2003) and Hinds, Patterson and Pfeffer (2001) found that during novice–expert interactions it is important to bridge the knowledge gap that exists between them. These studies, however, only described the need to get the novice up to speed with the experts' expertise; in the situation of design consultation meetings, we also found the need for sharing project and process information from the novices' side in order to get the expert up to speed with the novice's design problem.

Furthermore, the findings indicated that the times spent on the three main phases changed across the design process stages: the time spent on information seeking decreased whereas the time spent on knowledge creation increased. The time spent on context shared remained the same across the design stages. Since the novice and expert are more involved in knowledge creation compared to information seeking, and that the time spent on this phase increased over the course of the design process, this could be an indicator of the importance of the expert's experiential knowledge in the novice's design project.

As knowledge creation episodes co-occurred often with interactive conversation modes, potentially involving in a deep discussion is more important in a consultation than querying the expert, especially during the later stages of the design process.

Furthermore, it was found that the three phases alternated often. This finding could be an indication that the phases are dependent on each other; without sufficient contextual information sharing between the two parties, the novice risks both asking questions that do not fit the expert's expertise and that a solution generated by the expert during knowledge creation does not fit the novice's design problem. Since the phases alternated often between contextual information sharing and knowledge creation, it seems that during the meeting the novice and expert repeatedly need to share more context information before they can continue gathering and creating knowledge. Clark and Brennan (1991) stated that during a conversation, speakers constantly need to update their *common ground* moment by moment. They stated that actions executed collaboratively must be build upon common ground between speakers. This constant process of creation common ground can explain the often alteration between the phase; perhaps what Hinds identified as bridging the knowledge gap can be done by means of the process of grounding, which in our study was manifested by the often phase alteration.

5.1 Limitations

The major limitation of this study is the small number of analyzed meetings. Since we adopted a detailed analysis strategy in this research, analyzing a larger number of meetings is challenging. Additionally, the meetings were gathered in one specific field of NPD, namely the aerospace industry, and in only one company, which could have influenced the findings.

5.2 Suggestions for further research

To overcome the previously mentioned limitations, it would be interesting to investigate meetings between novices and experts in different organizations and in different fields of design engineering to be able to improve the external validity of the research results.

Furthermore, the finding that the phase alternated often could be further investigated by analyzing how the interaction changes and what the results for the conversation are. By means of such an investigation, the mechanisms that novices and experts can use to create common ground during these consultation meetings can be identified.

Additionally, the behavioural patterns as identified for the novices, could also be identified for the expert. As was stated repeatedly in this thesis, the role of one cannot be understood without understand the other's role. Therefore, a more detailed investigation of the expert's behaviour and the results of his or her behaviour for the consultation discourse could be further investigated.

5.3 Implications for managing knowledge in NPD

On the practical level, this study contributed by identifying the main processes occurring during novice–expert consultation meetings. By unravelling processes, activities and conversational balances of the meetings in general, structures and relations appear that can help novice and expert designers by increasing their understanding of elements in the conversation that are of importance to facilitate the meeting. When novices and experts are more aware of the main processes occurring during consultations, and perhaps more importantly the dependencies between these processes, the effectiveness of the meeting could increase.

In order to provide the novice designers undertaking the Design and Make project at Rolls Royce, with the lessons learned from this study, we designed a poster that provides novices with directions for improving their interaction with the experts. The poster is currently used during the Design & Make project for novice design engineers to communicate different benefits of gathering expert input during design projects. The poster distinguishes between three different types of novice knowledge needs in which experts can provide help during: (1) problem understanding, (2) design input and (3) organizational understanding. Per category, different sub-categories are identified and explained on the poster. A more elaborated explanation of the poster and its application will be reported in future.

One of the important implications for the novices is that their project knowledge must be extensively shared with the expert in order to have an effective consultation. For novices it might seem strange that sharing their knowledge is of much importance. In addition, experts might act as if they already understand the novices' design problems. For the novices rests the task to validate whether the expert's understanding of their design problem is indeed correct.

Based on the finding of this research, novice designers can be supported by our identification of what experts can contribute to their projects and how this can be achieved. Based on the found behavioural patterns and the corresponding effects on the conversation, we feel that novice will become more aware of the effect of their behaviour, which could result in the usage of these behavioural patterns as strategies in order to increase the effectiveness of the consultation meetings between experts and novices.

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