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TACIT KNOWLEDGE AND SITUATED PRACTICE IN NPD: AN IN-DEPTH CASE STUDY

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ABSTRACT

This paper describes a study of knowledge and learning in NPD. For the empirical data collection, one organization took part in an in-depth case study. Multiple sources of data were used, including interviews, repertory grids, and company documentation. In addition, we participated in a post-project review. As a result of our analysis, some key themes are identified, each of which has a significant impact on knowledge flow at the task level. Our analysis of a project shows that the top lessons learnt are complex; they relate to several key themes. This detailed investigation of situated practice highlights important implications for managing tacit knowledge and improving knowledge flow in NPD.

INTRODUCTION

New product development (NPD) is a knowledge intensive activity, in which learning and knowledge generation are critical to performance. Learning from NPD can generate competitive advantage (Corso et al., 2001), and so it is important to understand the mechanisms by which learning takes place. Managers responsible for NPD teams face a real challenge in attempting to maximize learning, especially as much of the expertise in an R&D department is based on tacit knowledge. If NPD teams fail to learn, similar mistakes are made (Meyers and Wilemon, 1989). Investigating knowledge creation and learning within NPD is difficult because previous empirical research is scarce (Busby, 1999; Schindler and Eppler, 2003), and extant studies have often neglected the organizational learning literature (Saban et al., 2000). Organizational learning is supported by personal and team reflection (Tsoukas and Vladimirou, 2001). However, it is also a dynamic, complex, and multifaceted issue that must take account of individuals and organizations as part of the learning context. A theoretical perspective that takes account of this complexity is *situated practice* (Gherardi, 2001). Situated practice indicates a deeply contextual, improvised, social activity that simultaneously applies and changes what people know (Orlikowski, 2002). It has received relatively little attention in the NPD literature, therefore this study attempts to apply a situated practice perspective to a study of NPD. This includes a discussion of the application of tacit knowledge, knowledge generation, and knowledge flow. Tacit knowledge generation and sharing is thought to depend on social interaction and shared experiences (Thomke and Fujimoto, 2000; Nonaka, 1994; Wenger and Snyder, 2000). However, a good deal of confusion and controversy remains over whether, how or even if tacit knowledge can be identified (Fernie et al., 2003; Gourlay, 2006), let alone captured and shared.

Our study of learning and tacit knowledge in an NPD environment builds on the methodology of a previous study (Koners and Goffin, 2007). For the empirical data collection, one organization that we refer to as ValveCo (an innovative leading producer of electro-mechanical devices) took part in an in-depth case study. Multiple sources of data were used, including interviews, repertory grids, and company documentation. In addition, we participated in a post-project review.

Although our study reports on a single case, the detailed investigation of situated practice highlights important implications for managing tacit knowledge and improving knowledge flow in NPD. It illustrates some key factors which can enable or retard these processes. Finally, it identifies a number of possible ways in which knowledge and learning can be better managed.

The structure of the paper is as follows: first, the research method is described in detail, followed by the results. Then, given the context provided by these results, our case study project is described. Finally, a summary is given, describing the implications of our findings for learning and knowledge flow.

RESEARCH METHOD

In this paper we describe one project in detail in order to provide insights for learning through illustrations of situated practice in NPD. The project we are focusing on developed a novel product; no similar products were available in the market. Project scale was approximately 4 years duration and 20 full time personnel. Multiple sources of data were used to provide a rich contextual background, enabling a description of situated practice in NPD. The research methods include a group brainwriting session, repertory grid interviews, and company documentation. In addition, we participated in a post-project review. Each method gives a different output, as illustrated in figure 1.

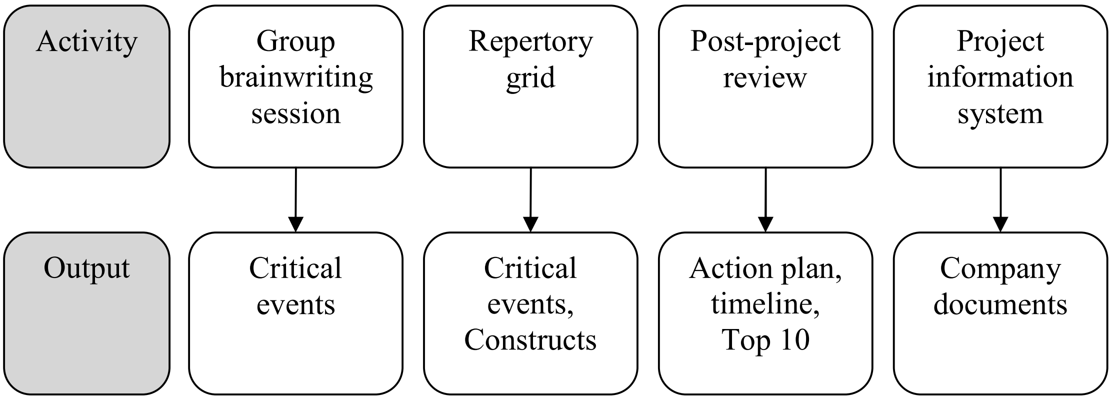

Figure 1: research method activities and outputs

Group brainwriting session

A group brainwriting session was organised with the aim of identifying critical events and their outcomes. 9 people participated in the session from 7 departments including purchasing, design, production, engineering, and quality. These were experienced participants; the average length of service with the company was 21 years.

Participants were asked 2 key questions:

- “For each of the projects you were involved with, think of the critical events that took place. Write a description of that event on a giant post-it, in 3 lines or less, in large, clear writing using a marker pen.”
- “Briefly describe the outcome of each critical event on another giant post-it, in 3 lines or less, in large, clear writing using a marker pen.”

(The emphasis on large writing was to ensure that members could read each other’s writing from across the room when the results were presented.)

Each participant was then invited to stick their post-its on the wall, and to describe the critical events and their outcomes. 46 events were identified in total. There was a short time for discussion at the end of the session, to identify some common themes and to give feedback.

In addition to the short time spent identifying common themes in the session, qualitative analysis was carried out to identify event categories. This activity was carried out by one researcher only, which (as discussed in the analysis of the repertory grid constructs) means that the reliability of the resulting categories is questionable. However, given the relatively better understood domain, the reliability is expected to be acceptable.

Repertory grid method

The aim of the repertory grid activity is to elicit a number of *constructs*. A construct indicates the way in which an individual construes, or anticipates, critical project events. Repertory grid interviews were carried out with a total of 17 participants. In each case, the same protocol was followed. Following a brief introduction to the research, participants were asked to provide some details of their background, experience, and current role. The next stage was to elicit the elements, as the unit of analysis for the repertory grid activity. As with the group session, we asked participants to describe ‘critical events’. They were described as “events that had an impact on the progression of the project, that were either positive or negative”. The participant had to be personally involved; the event was critical from their perspective. We explained that the mechanics of the next activity required between 6 and 10 events. When it was apparent that the participant was having some difficulty in thinking up new events (and we had more than 6), we moved on the repertory grid activity. Preparing for that activity, the events were written onto cards, and assigned (pre-defined) random numbers to change the order in which they were given.

Predefined sets of three cards (triads) were then presented to the participant, and they were asked “Tell me something that any two of these have in common that makes them different from the third”. If their response presented a clear construct, they were then asked “how would you describe the other(s) in contrast”. If the construct was not clear, they were requested to clarify by asking “is that an important distinction?” or “why is that an important distinction?”. Questions to the participant to clarify or explore were always asked using their words, where possible. The key strength of the repertory grid method as an interviewing technique is the removal of interviewer bias. This is achieved by removing the opportunity for the interviewer to add their own interpretation. As such, it was very important to stick to the protocol as much as possible, and where additional probing was needed, to reflect back using the participant's own terms.

Once the constructs are elicited, participants are asked to rate the *elements* according to the elicited *pole* and *counterpole* of the construct. A score of 1 represented the pole, and a score of 5 represented the counterpole. As an example, the construct pole elicited from participant #11 'I have an influence' has the counterpole 'I can't influence it'. In the example, a rating of 1 would represent a lot of influence, and a rating of 5 would represent little or no influence. They were asked to rate the three cards, and then all of the remaining cards, based on this scale. This process of presenting element triads to elicit constructs was repeated until the allotted 90 minutes were up.

Due to the requirements to identify and clarify constructs, to probe the participants in an unbiased way, and to manage the mechanics of the interview, experience with the repertory grid method provides some advantage.

Qualitative analysis of the repertory grid data: defining construct categories

In the qualitative analysis process for the repertory grid constructs, care was taken to create a set of reliable and valid categories. For the coding process, a set of 155 cards was created: one for each construct. Each card was created using a template including the following data: participant ID, construct, counterpole, and description/quotes. An example construct card is shown in figure 2. The description/quotes were created by listening to the interview transcript and identifying the key phrases or terms that were used in defining or describing the construct. The purpose of including this description was to provide extra contextual information to aid the coding process. As an illustration of how this description can influence the result, the example in figure 2 was initially coded by one researcher as *internal to department*, and by the other as *mandatory legislation*. It was finally coded by both researchers in the *legislative constraints* category. Since the construct and counterpole title do not reference legislation, the final coding was dependent on the description.

ValveCo

Participant #3
Construct #4

Construct

Externally approved design

Counterpole

Internally approved design

Description / quotes

[this one] requires certification that is supplied by a 3rd party, external body... we are following laid down legislation. The design authority is outside. [this one] just has to meet our internal requirements. We are the design authority.

Figure 2: example construct card

Two researchers completed the coding process independently, each creating their own set of categories. One researcher created 23 categories, and the other 31. A 23×31 reliability table was created to identify the level of agreement. Those categories with the highest level of agreement were placed at the top of the table. The top 5 categories are shown in figure 3.

	Researcher 1				
Researcher 2	Control	Departmental Divisions	Suppliers	Customer Issues	Design Process Milestones
Within the group control to change	V2/7, V6/1, V7/8, V7/10, V10/1, V11/6, V12/4, V13/2				
Internal to department		V2/11, V4/3, V10/3, V10/9, V10/12, V11/2	V13/5		
Supplier issues	V8/1, V10/7	V6/4	V6/2, V6/6, V8/4, V8/5, V8/6, V14/11		V11/4
Design - customer driven				V3/5, V4/8, V9/4, V10/10, V12/3	
Production issues		V11/5, V11/7, V17/7			V6/9, V8/2, V8/7, V9/2

Figure 3: part of the reliability table following the first coding exercise

The inter-rater reliability from this first stage was 40%. That is, the number of constructs that appeared in the diagonal was 40% of the total. In the example in figure 3, the second cell in the bottom row is not included in this figure. Although there is some agreement, another cell has a greater number of constructs that are aligned (the fifth cell has four constructs). Only those cells with the highest alignment appear on the diagonal, and get included in the inter-rater reliability assessment. Low reliability is not unexpected for independently coded qualitative data, but it does demonstrate a need for clarity in the category definitions.

The next step was to create a refined set of categories. The two researchers had a discussion to identify similarity and differences in their categories, using the reliability table to see any differences in how they had assigned individual constructs. A refined set of 24 categories were then defined (23 + *other*), with descriptions outlining what was to be included and excluded. Finally, the two researchers repeated the coding process using these defined categories. A new reliability table was created, showing the inter-rater reliability from this stage as 69%. Given the lack of an accepted threshold for this type of data analysis, we accepted the value of 69% as reflecting an adequate level of definitional clarity. This is in part because an evaluation of the non-correspondent results showed that several of the constructs could clearly fit into two categories. This is due to the use of both construct poles in our evaluation. The nature of personal constructs is that the pole and counterpole *are not opposites*, but together describe one way in which an individual construes the domain. For example, *internal issues* is not the opposite of *outsourcing* (construct #7/1); *legislation standards* is not the opposite of *usage in the field* (construct #3/3). In addition, the open nature of our approach meant that the resulting responses were not specifically focused towards a particular area. For example, in a previous study by the authors investigating post-project reviews, our question in the repertory grid interviews "how are two of these projects similar and different to the third" included the additional phrase "in terms of what you would do differently if you were doing the projects again" (Goffin and Koners, 2010). In this study, we only asked "Tell me something that any two of these have in common that makes them different from the third", with no further detail. The open nature of our questions has both positive and negative outcomes: positive because it gives a very personal view of how people perceive problem events, and negative because it complicates any attempt to assess similarity. This tension between individual and group level relevance is a continuing theme, given the premise that organizational routines will be created and managed at the group level. Perhaps, given sufficient knowledge and insight into the needs of an individual and the factors that influence particular behaviours we can begin to extend beyond the command and control paradigm, towards a co-managed, self-regulating innovation system.

Whilst we considered that our method had an acceptable level of reliability, the evaluation of reliability may not be entirely necessary in an exploratory research process, particularly given the contextual and personal nature of situated practice. However, we felt that seeking and measuring reliability did not detract from the value of the findings. It also indicates the level of agreement that this exploratory research method can realise, which is itself an interesting finding.

Post-project review

The aim of the post-project review event is to reflect on the key lessons learnt from the project, to share them within the group, and to apply those lessons to future projects. Two of the authors participated in the post-project review event. Since this was not an activity that the company would typically run, we created the agenda and facilitated the day. The majority of the project team (19 people) attended the event, representing a range of disciplines including, for instance, mechanical, electronics and manufacturing engineering, purchasing, quality, manufacturing operations.

Following an introduction to the day and an overview of post-project review events, the group was split into two for the activities. One group created a *timeline* of the project. This involved writing colour coded task descriptions, milestones, and positive and negative events on post-it notes and sticking them to the wall. The other group were asked to share their *key lessons*: "What key lessons would you like to pass on?" Since the reliability of market data was discussed as a key theme in earlier sessions, the second group then took part in a brainwriting session to generate ideas for gathering reliable *market data*. Following a combined feedback session, the two groups then divided and each created a list of their *top 10 lessons learnt*, before coming together and creating a collective top 10. An *action plan* was then created based on these lessons for 2 forthcoming projects.

The outcomes of the PPR were collated in a report, which was validated by the senior managers who took part in the event.

Project information system

The project information system was used in order to clarify and verify a number of findings from the other research methods. The project manager described how to use the system, and one of the authors spent a day looking through the project files. A number of documents were requested and made available as an additional source of data. Key sources to triangulate some of the key events include the product specification, and minutes of meetings. In addition, company documents describing the NPD process were provided. The company documentation served as a means to triangulate the accounts of key events described in the interviews and PPR.

RESULTS

Critical events: what events are important?

A coding exercise was carried out to categorise the critical events that were identified in the group brainwriting session and in the repertory grid interviews (elements). A total of 206 events were described, and 29 categories created. The top 15 categories are shown in table 1, representing 177 (86%) of the 206 events.

Table 1: critical event categories

Category title	Technical challenge	Certification & Approvals	Supplier selection	Comm-unication	Supplier problems
# in category	22	18	15	14	13

Category title	Major milestone	Time pressure	Product strategy	Product Testing	Prototyping
# in category	13	11	11	10	10

Category title	Engineering Change	Pre-production prep	Spec change	Weak design review gate	Supplier evaluation
# in category	9	9	8	7	7

The most commonly reported critical events are in the technical challenge category. This reflects the nature of the sample. Of the 26 people involved, 21 were in technical roles (e.g. mechanical design, electronics design, and production), and 5 were in non-technical roles (e.g. purchasing). Addressing technical challenges is a key aspect of a technical role. The second most commonly reported critical events are in the certification and approvals category. This reflects the challenges faced in serving highly regulated markets with strict certification and approval requirements. The third most commonly reported critical events are in the supplier selection category. The high importance of suppliers follows the strategy to assemble products in-house using bought-in components. Overall, there are three categories referring to suppliers (selection, problems, and evaluation), which together account for 35 events. The fourth most commonly reported critical events are in the communications category. In a dynamic, distributed engineering project, communication is critical. Supplier problems are fifth. Again, the impact of the purchasing strategy is reflected in this category. Project milestones were the sixth most frequently reported, followed by time pressure. These events give an indication of a target driven project environment. Other notable categories are spec change and engineering change. It is also interesting to note that of the 60 events reported in the group brainwriting session, 20 occurred during the same project. This project was the subject of the PPR, and is the focus of our analysis.

Construct categories: how are these events thought about?

The construct categories, as defined collectively by two researchers, are shown in table 2. The number of constructs in a given category indicate the likelihood that an individual will mention a specific factor. We did attempt to apply variability (sum of squares) as a means to measure category importance, however because the method for combining frequency and variability (to indicate importance) is not well documented, it is not included in this analysis.

Table 2: construct categories and definitions

Category Title	Description	Any exclusions	# in category
Departmental activities	What a department does / how departments interact	Supplier / communication issues	12
Supplier Issues	Relates to suppliers	Legislative constraints	12
Control - organizational	Control at the organizational level, 'in our control'	Individual level	10
Design process phases	Importance of a particular phase in the design process		10
Difficult problem solving	Problem solving that was difficult		10
Constraints	Constraints, including cost	Legislative constraints	9
Product function	Describing how product function is met or interacts with physical, mechanical, or other properties		9
Specification	Quality, understanding, changing, achieving		9
Communication	Communication taking place (or not) including inter-departmental	Supplier issues	8

Category Title	Description	Any exclusions	# in category
Customer issues	Something that has an effect on the customer, or is of direct interest to them		7
Project plan - keeping to plan	Sticking to the project plan, unforseen changes or events	project / process phases	7
Testing	Testing, e.g. physical or practical tests		7
Design changes	Changes made to the design		6
Knowledge in a particular area	Depth of knowledge in a specific area	Breadth of knowledge	6
Control - individual	Control at the individual level, 'in my control'	Organizational or departmental level	5
Future projects / products	Issues for future projects or products		4
Legislative constraints	Legal requirements or standards that must be met		4
Management impacting design	High level decisions impacting the design	Cross-departmental	4
Resources	Influenced by resources (esp. money)	Knowledge / experience	4
Broad knowledge and experience	An individual has a lot of knowledge	Problem solving / Depth of knowledge	3
Commercial Vs. Technical	tension between commercial and technical		3
Cost as a driver	Cost influences the design	Constraints	3
Narrow or wide range of people involved	Few people or many people involved in an activity		2
Other	-	-	3

Alignment of Critical Event and Construct categories

The top categories of critical events that we have selected for further analysis include technical challenge; certification; supplier issues (selection, problems, evaluation); communications; project milestones; and change (including specification and, engineering change). The key construct categories that we identified include supplier issues; design process phases; departmental activities; design changes; project plan; constraints; and communication. A summary of the key critical event and construct categories is shown in table 3. This table shows a very close alignment between the key event and construct categories, and gives some additional insight into how the critical events are thought about. For instance, technical challenges are thought about in terms of their difficulty. The individual constructs show that technical challenges relate to the application and high value of expertise in solving difficult problems. Supplier issues were shown to be critical because of the manufacturing strategy, so special attention must be paid to supplier selection and involvement. Communications are a key factor in the NPD process, especially across departments. Sticking to the project plan is also looked upon as critical, due to the deadline driven environment. Change is also a key factor, including engineering change, design change, or specification change.

Table 3: Key critical event and construct categories

Critical event categories	Construct categories
Technical Challenge	Difficult problem solving
Certification	Constraints Legislative constraints
Supplier issues	Supplier Issues
Communications	Departmental activities Communication
Project milestones	Design process phases Project plan – keeping to plan
Change	Specification Design changes
-	Control

One key construct category that is not obviously aligned to any single critical event category is control (both organizational and individual). Whilst some of the control issues relate to constraints (e.g. specific manufacturing or supply chain constraints removing an element of choice), there are also many instances referring to interpersonal control, i.e. in terms of *influence* or *negotiation*. There is also an association between control and *management impacting design*. The locus of control is a key issue to consider in terms of how it impacts on individual motivation, satisfaction, and task success. In the following section a recently completed project is described. We then examine the ways in which the project relates to these key critical event and construct categories.

INVESTIGATING SITUATED PRACTICE: THE CASE STUDY PROJECT

A project recently completed will be briefly described. A new technical solution had been identified that could offer a lower cost and higher performance solution within an existing system. Several aspects of technology used in the new product were new to the company, and new to the market. As such, the product represented a high degree of technical and market novelty. The project scale was approximately 4 years duration, with 20 full time personnel during the detailed design and implementation phases. In line with the company manufacturing strategy, a high proportion of the product components and subsystems are manufactured by their network of suppliers. Important aspects of the project context are highlighted:

- Large scale project
- Technology driven
- Novel product type
- Uncertain market demand
- High level of outsourcing

Key issues and events in the project

The project started very positively, with a small team developing a design concept, and building a physical prototype. At the end of the prototype phase, they had a proof of concept that the technical team were quite happy about. Shortly after the project shifted from prototype stage to a full scale design project, a change was specified based on feedback from marketing. What appeared at first sight to be a relatively minor change to resolve an aesthetic issue was actually a major technical change. Reflecting the perceived lack of importance at the time, this decision to change the product structure was not clearly documented. As the project progressed, a combination of time pressure and design flux led to a number of coordination problems. One comment was made illustrating the outworking of the coordination challenge: "At version 3, purchasing promised the supplier they would stop changing the design. By version 21, the design was actually fixed". Often, technical challenges identified through testing meant that the design had to change in order to achieve the requirements. Because the product also had to meet various accreditation criteria, some of the components were submitted to an externally managed, costly and lengthy process of certification. The top 10 lessons learnt, as identified in the PPR, will be used to direct further discussion of the key issues and events experience in this project.

Top 10 lessons learnt

1. Dark orange syndrome: *Don't bulldoze through red lights*
2. Deadlines can drive the pressure to continue through technical red lights (*dark orange syndrome*)
3. A clear and agreed specification, with WOW factor, should be agreed up front
4. Get production input early, including suppliers
5. Pre-production trials should not be treated as the production launch
6. Ask the right questions (of suppliers) to check progress
7. Red lights identified in design review must be followed up; reviewed again
8. Decisions should be transparent between sales and technical
9. Define clear deliverables for each work package
10. After the prototype review, any spec change must be signed off by the design owner

The lessons learnt, as defined by the project team, reflect their key concerns. First, the team identified the lesson *don't bulldoze through red lights*. The second lesson refers to the same issue, discussing a specific deadline driven by an external event. The key problem that they had identified, and that took place during this project, was the decision to continue following the project plan even where a technical review had identified a 'red light'. A technical red light indicates that a significant issue must be resolved before any further work takes place. Red means stop. The decisions to continue were attributed in part to time pressure, although a major factor was the relative balance of power and authority in the review team. Where a director stated that the product had to be delivered, the response of the project team was to forge ahead regardless of the technical red light. This strategy is one of the major factors that caused stress and upset for the project team members and suppliers. It is also a highly complex issue, affecting all of our key critical event and construct categories (excepting legislative constraints). It relates to power (*control*), *project milestones*, *communication*, and has an impact on *change* and *supplier issues*.

The third lesson is to create a clear, agreed product specification up-front. The discussions in the PPR also led to the inclusion of WOW! factor. That is, from the perspective of the customer, the product spec should represent such significant value that they say WOW! Whilst the lesson refers to defining an agreed spec up front, the reason for this lesson being so prominent is the major coordination problems caused by any changes to the product during the later stages of the design process. In this project, the tension between the use of structured management methods and the development of a highly novel product were apparent. In order to coordinate a concurrent engineering project, design has to be fixed in various stages. When one aspect of the design is fixed, other components or systems that rely on or interact with that aspect can subsequently be designed. Periodic testing showed how well the design was able to meet the various technical criteria. In some cases, the actual technical capability (as identified through testing) did not meet the requirements. This dynamic interaction between specifications and technical capability was a major contributor to design change. Where the technical capability could not be met, the specification would change. Where the specification could not be changed, the product design had to change. Changes to any single aspect of the design had to be evaluated for knock-on effects. In some cases, these knock-on effects were significant. The uncertain requirement combined with an uncertain technical capability caused this dynamic flux, and led to coordination problems. Two important factors here are the highly constrained (market) environment, and the uncertainty associated with significant novelty. A third important factor is the analysis of change impact, which is the subject of lesson 10. Some changes may initially appear minor, but actually have major knock-on effects. Any proposed changes must therefore be reviewed and signed off by the design owner. A number of the project team felt that the early product change caused these coordination problems because it modified a fundamental aspect of the mechanical system. The results of changes to the product design and specification are associated with most of the key categories: a *change* caused by a *technical challenge* within *constraints* causes problems with the *project milestones* as well as *supplier issues*.

Lesson 4 suggests that production input should be sought early on, including input from suppliers. The lesson was prompted by the discovery of a number of quality issues with supplied items at the production trial stage. The need for close contact with suppliers in co-developing new products is in conflict with the purchasing strategy of competitive supplier selection based on a completed design specification. In some industries (e.g. automotive), the power of the OEM is such that they can demand that the supplier produce a design solution and prototype product in order to bid for the supply agreement. However, smaller supply chains are generally not able to request significant design effort without prior agreement to purchase from that supplier. If manufacturing constraints and supplier expertise are not known in advance, there are more problems associated with late stage supplier selection. It is less likely that the OEM design team would have specific manufacturing methods expertise when developing a novel product, particularly if it uses materials or methods that are new to them. Time delays and design changes are very costly at this late stage. This lesson is related to many of the key categories: the *technical challenge* of design for manufacture is associated with a number of, *constraints*. This may cause a number of *supplier issues*, which could have been resolved by improved *communications* with the suppliers. The resulting problems are a potential source of delays for the critical *project milestones*.

Lesson 5 refers to the supply chain readiness and design fix status at production trial stage, compared with production launch. The project plan allows for a degree of flexibility in addressing any issues identified during the production trials. The time pressure in this project led to a number of these key issues being dealt with as if it were the production launch. Whilst on the surface this is simply a matter of sticking to the guidelines specified in the project plan, in terms of design fix and supply chain readiness, it also refers to the way that project slippage is handled. Coordination of the various supply chain aspects can not, according to this lesson, be allowed to change in order to treat the trial phase as a launch by fixing designs and purchasing production quantities from suppliers before the product readiness has been achieved and verified. This lesson relates to the following key categories: *supplier issues* and internal coordination problems can be caused by a lack of internal *communications* about the status of *project milestones* within which a degree of *change* is expected, and is still acceptable.

Lesson 6 – ask the right questions – refers to the way of getting status updates from suppliers, particularly those from other cultures or nations. People from other cultures may not respond to the intricacies of the local (British) culture in the same way as a local. As such, questions relating to the status of a project must be asked directly, and clarified, in order to ensure that both parties have understood. The indirect question “is everything going OK” may be taken to mean “should I still expect to receive my delivery on time and to specification” by a UK national. If the supplier responds “yes everything is OK” this may not refer to an on-time delivery, or to a lack of quality problems being faced at that time. The lesson here is to ask the right questions in order to clarify understanding. This lesson refers to the key categories *supplier issues* and *communication*.

Lesson 7 (in addition to lessons 1 and 2) also refers to red lights, suggesting that they be reviewed and followed up. This relates to the key categories of *communication*, *project milestones* and *change*.

Lesson 8 refers to the need for transparent decisions between sales and technical. This refers to the recognition of the impact on the project of making changes in the later stages. Specific changes that were discussed relate to market led decisions such as changes to product specification. This is very closely related to lessons 3 and 10, in terms of the recognition of the high impact of design changes in late stages of the design process.

Lesson 9 refers to the need for clear deliverables for each work package, as a matter of to improve project clarity and coordination. If work package deliverables are not clearly understood, then this could cause problems. This lesson relates to the following key categories: *communications* and clear descriptions can improve the understanding of the exact nature of the *Technical Challenge*, which can have an impact on the performance of *project milestones*.

Lesson 10 states that any spec change after the prototype phase must be signed off by the design owner. This is similar to lessons 3 and 8, in terms of the recognition of the high impact of design changes in late stages of the design process. The numerous impacts of late stage design change are discussed alongside lesson 3.

Product novelty brings uncertainty

Of the top ten lessons learnt, five (1,2,5,7,9) relate to project milestones and coordination, and three (3,9,10) relate to specification (of products or tasks). One theme among the top10 lessons is that of certainty. This exists in terms of early supplier input, clear task definition, uncertain product specification, clear sales / technical decisions, design changes, and reviewing red lights. Following the descriptions of the key lessons, it is apparent that product novelty causes uncertainty at the individual task level, which in turn brings uncertainty to the project schedule.

Project milestones in this project were described by one respondent as a "moving goalpost". The certainty of specifications is important, since they define the work that is required of the project team. Regarding the emergence of product requirements in this project, one respondent referred to them as "nice to have, never written down deliverables". This refers a perceived lack of clarity with regard to the specific nature of the product requirements. The issues of project coordination and specification clarity are interrelated. Product novelty is a major challenge for product coordination, since a novel project by definition includes some things that are not known. Where product elements are unknown, an iterative design and verification process will be applied, resulting in a number of product changes. Any product change must be carefully managed and coordinated across the whole design team. For this reason, design changes can take a long time, especially if interacting elements have been fixed. The number of these iterations and changes that must take place is not known in advance, and partly depends on how well the technical issues are understood. The technical challenge that novelty represents therefore impacts on schedule uncertainty. This problem is amplified in a highly constrained system. Where highly regulated products require external approval, the approval process will also result in time delays. Scheduling in the approval process for each component may mean that a component design has to be fixed. Any subsequent changes that may be required are therefore highly constrained. Thus there is a tension between design flexibility to allow for technical discovery, and design stability to allow for certification and manufacturing planning.

In planning a new project the degree of schedule flexibility allowed for technical discovery should take account of product novelty (technical uncertainty).

Product novelty requires closer supplier interaction

A need for early supplier interaction was highlighted as a key lesson from this project. Given relatively lower technical understanding, the emerging requirements for the parts being supplied were not known to the design team at the early stages; and sometimes after they had received the parts. It was also highlighted (with examples from a previous project) that the specific expertise of the supplier is important, in terms of their ability to make an expert evaluation of the specific issues that they, and the design team, need to consider. It is in these emerging issues that tacit knowledge (i.e. the application of expertise) is most apparent. An evaluation based on a discussion will consider additional factors, including probing as yet unidentified issues, and picking up on contextual signals. This partially explains the benefit of face to face contact in areas that are not fully understood or complete.

SUMMARY: LEARNING AND KNOWLEDGE FLOW

Whilst this analysis has largely focused on the negative aspects of the project, we should also reflect that the project achieved the requirements with only a small degree of schedule slippage. The key factor was not the ability of the design team to realise a high quality design, but the relatively higher level of stress caused by various aspects of this particular project.

The key categories of issues and events in the project have been discussed alongside the top 10 lessons learnt. These key categories of issues and events were identified as being important to the case company in two ways: the types of critical events that occur, and the ways in which those critical events are important. We found a good deal of crossover between these two sets, and the combined list includes: technical challenge, constraints, suppliers, communication, project milestones, change, and control.

The illustrations of situated practice in NPD provide a number of insights for NPD learning and knowledge flow. Here we will outline some of the factors which appear to enable learning and knowledge flow, and some possible ways in which knowledge and learning could be better managed in NPD.

- The post-project review (PPR) gave a great deal of insight into what the project team learned; a top 10 list of lessons was created.
- In addition to the PPR, the repertory grid analysis of critical events and subsequent coding showed various important categories.
- Each of the key categories (technical challenge, constraints, suppliers, communication, project milestones, change, and control) has a major influence on knowledge flow at the task level.
- An analysis of the lessons learnt in light of these categories highlights that the lessons learnt are highly complex and interrelated; they each relate to multiple categories of critical events and constructs. As such, learning and knowledge flow are shown to be complex, situation specific, and contextual.
- Uncertain projects need a different approach
- Communication is especially important in uncertain NPD

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