In this paper, we argue that ambiguity is an essential component of “fuzziness” in the Fuzzy Front End of New Product Development (NPD), and that a better understanding of how ambiguity emerges and is reduced, is called for. We explore the process by which ambiguity was reduced in four NPD projects, and propose a model that enhances our understanding of this process. Ambiguity arises as multiple interpretations, and interpretations can be understood as hypotheses, hence these can be tested by using the hypothetical-deductive method (HDM). We present a model showing that ambiguity in NPD projects is efficiently reduced by applying the HDM to test the multiple interpretations that give rise to ambiguity and the assumptions underlying these interpretations. We discuss theoretical implications and the usefulness of the model for practitioners of NPD.

Keywords: New product development; ambiguity; qualitative analysis.

Introduction and Background Theory

The importance of New Product Development (NPD) in helping to ensure a firm’s competitiveness is well recognised; consequently, there is also a recognized need among researchers and practitioners for efficient ways to manage NPD processes. Many of the models that have been developed for this purpose are the so-called “stage-gate” models (Myrup and Hein, 1987; Cooper, 1990). They emphasize
up-front data gathering and planning followed by subsequent execution. While they have been found to work well in relatively stable industry environments, they may be less suitable for radical innovations (Veryzer, 1998) or innovations in more dynamic industry environments (Eisenhardt and Tabrizi, 1995; MacCormack et al., 2001). The earliest stage of an NPD project is especially prone to manifesting a high degree of uncertainty and ambiguity, characteristics that do not fit well with approaches requiring accurate up-front information. This phenomenon is commonly recognised in the literature as the “Fuzzy Front End” of NPD (Moenaert et al., 1995; Khurana and Rosenthal, 1997; Reinertsen, 1999; Montoya-Weiss and O’Driscoll, 2000; Reid and Brentani, 2004). The front end is the starting point that determines the direction of the NPD process. Fuzziness at the front end that is not reduced, but carried through into the NPD process may therefore lead to excessive costs in the NPD project due to failed investments and corrective actions as well as to time overruns. Reid and Brentani (2004) have argued that a better understanding of the fuzzy front end can ultimately lead to competitive advantage, since actions taken to improve the NPD process at the fuzzy front end, when the NPD process is still at the idea stage, are more cost-efficient than actions taken during actual implementation of a product idea. This entails that a better understanding of not just what fuzziness is, but also how it can be reduced will be an important contribution to improve the efficiency of NPD processes.

To alleviate the problems of the fuzzy front end associated with the sequential approach of stage-gate models, alternative approaches emphasizing flexibility and iteration have been presented (Eisenhardt and Tabrizi, 1995; Verganti, 1999; MacCormack et al., 2001; MacCormack and Verganti, 2003) and claimed to be better suited to manage uncertainty in NPD processes. However, theories specifically addressing the nature and management of ambiguity, as distinct from uncertainty, in NPD projects are missing. As we will describe in the following section, we argue that ambiguity is different from uncertainty, and is an important part of “fuzziness” experienced in NPD processes.

Our research objective, therefore, is to:

— explore how ambiguity emerges in NPD projects and how NPD project participants respond in ways to reduce this ambiguity.
— develop a model that explains how participants in NPD projects can reduce ambiguity.

We believe such a model will contribute to a better theoretical understanding of ambiguity reduction in NPD processes. It will also be helpful to practitioners as a tool to reduce ambiguity — and thereby reduce fuzziness — and thus run their NPD projects more efficiently.
Ambiguity and uncertainty

Our approach in this paper is that fuzziness can be understood through the terms uncertainty, ambiguity and equivocality that have been commonly addressed in the literature of organisation and management theory. We will review the literature on these terms as we see them relevant to NPD processes.

A suitable starting point is Daft and Lengel’s contribution on organisational information requirements (Daft and Lengel, 1986). Whenever an organisation’s information requirements are not met, we are experiencing either uncertainty or equivocality (Daft and Lengel, 1986). Uncertainty, they say, means the absence of information. As information increases, uncertainty decreases. The degree of uncertainty may be defined as the difference between the amount of information required to perform a task and the amount of information already possessed by the organisation (Galbraith, 1977). As new data are acquired, the task can be performed under a reduced level of uncertainty. As a contrasting term, they use equivocality, stating:

“Equivocality means ambiguity, the existing of multiple and conflicting interpretations about an organizational situation. High equivocality means confusion and lack of understanding. Equivocality means that asking yes-no questions is not feasible. Participants are not certain about what questions to ask, and if questions are posed, the situation is ill-defined to the point where a clear answer will not be forthcoming.” (Daft and Lengel, 1986)

The term equivocality is also used by Weick in The Social Psychology of Organizing (Weick, 1979), to denote the presence of two or more possible meanings for the same cue. Weick asserts that the need for reducing equivocality is the basic reason for organising, which he defines as a consensually validated grammar for reducing equivocality by means of sensible interlocked behaviors (Weick, 1979). In his later work, Sensemaking in Organizations (Weick, 1995), Weick introduces the term ambiguity, which he defines as a combination of two underlying terms: equivocality and lack of clarity. Lack of clarity, according to Weick, stems from ignorance, and is similar to uncertainty, which will be reduced by the availability of more information. Equivocality, on the other hand, stems from confusion, where two or more meanings can be assigned to the same cue. Resolving equivocality is possible not only by providing more information, but also by providing different kinds of information, constructed by face-to-face interaction.

In their contribution on Information Richness, Daft and Lengel (1984) sought to reconcile Galbraith’s conception from 1977 of uncertainty reduction (the notion that uncertainty can be reduced by processing sufficient amounts of information)
and Weick’s conception from 1979 of equivocality reduction. They defined information richness as the potential information-carrying capacity of data. Following this definition, rich information is understood both as information-carrying cues of multiple meaning and as information-carrying multiple cues. Examples of rich information are informal written and spoken texts, visual signs and body language, whereas numbers and formal texts are examples of lean information. According to Daft and Lengel, lean information is suitable for communicating well-understood topics and routine tasks, whereas rich information is suitable for communicating about complex topics. According to the authors, such complex topics are characterised by subjective, fuzzy cues and ill-defined events. These characteristics are, in our opinion, typical of NPD processes, particularly in the early stages.

March has mainly discussed ambiguity as an aspect of decision making. In March and Simon’s (1958) work on bounded rationality, the theme of ambiguity lies implicit in their discussion of how organisations consider available alternatives under limited access to information. In a more recent and comprehensive overview (March, 1994), March sharply distinguishes between ambiguity and uncertainty. He claims that uncertainty, in most theories of decision making, refers to imprecision in estimates of future consequences conditional on present actions. The basic assumption behind these theories, he claims, is that there exists an objective, real world that is imperfectly understood but that can, in principle, be discovered if enough information is made available. Ambiguity, meanwhile, refers to a state where the basic assumptions behind the view of uncertainty are challenged. Provision of more information may not in fact improve our understanding, and the world may actually be socially constructed rather than objectively real, meaning that it must be invented and negotiated rather than discovered.

In spite of certain differences in the definition of ambiguity, the perspectives set forth by Daft and Lengel (1984; 1986), Weick (1995) and March (1994) align rather nicely regarding the difference between uncertainty and equivocality. Developers of new products struggle with both uncertainty (e.g. not knowing the cost of a component) and equivocality (e.g. conflicting interpretations of a product idea or of a market need).

For the purpose of our study, we have chosen to operate with Daft and Lengel’s definition of ambiguity as synonymous to equivocality, i.e. the existence of two or more interpretations of a single cue. A cue in this respect can be an idea, a piece of oral or written information, a physical artifact or a situation. This is illustrated in a conceptual framework shown in Fig. 1. The lines represent the process of interpreting the cue, and each box at the right end of the line represents the result of the process — the interpretation of the cue. Several participants in the NPD process may interpret a cue, and ambiguity arises when the cue is assigned a multitude of interpretations, illustrated by A–E in our conceptual model. Participants in the NPD process experiencing this ambiguity will respond to it in some way.
We now turn to another view of uncertainty, commonly held in management literature and originally provided by Knight (1921). Knight discussed uncertainty related to probability judgement and identified three types of uncertainty:

1. When the outcome of an event is not known, but the probability distribution is known.
2. When the outcome of an event is not known, and the probability distribution is unknown but can be estimated statistically.
3. When the outcome of an event is not known, and the probability is unknown because a distribution is non-existent and cannot be estimated because we are dealing with situations that are unique, so statistical estimation based on a large number of homogeneous instances cannot be attained. In this situation, probability cannot be estimated and is not susceptible to measurement.

Knight used the term “risk” to denote the first two categories, which refer to measurable uncertainty, whereas he used the term “true uncertainty” to denote the third, immeasurable type of uncertainty. In Knight’s account of true uncertainty, the focus is on the probabilities of the outcomes of events. We note, however, that the events themselves are assumed to be known. The question we then pose is: What happens if there is no agreement on what the events are? We argue that it is in the understanding of the event itself that ambiguity first emerges, as illustrated in Fig. 2.

To illustrate with an example in the context of an innovation process, the process can be started by a cue, e.g. a business opportunity that is identified. Participants in the process will interpret this cue, resulting in a set of multiple interpretations (i.e. ambiguity) of what they consider sensible actions (e.g. new product ideas to pursue) to exploit this opportunity. The participants will then associate each of these interpretations, or alternative actions, with a range of outcomes (e.g. market success or market failure), which may also be ambiguous, and the probabilities of these cannot be determined (i.e. a situation of true uncertainty). In this situation of true uncertainty, ambiguity arises first, as multiple interpretations of the cue.
Subsequently, true uncertainty arises associated with predicting the outcomes of these interpretations. We believe situations like these are typical of NPD processes. Here, ambiguity is closely related to true uncertainty, but occurs both at a separate precursory level and later as a component of true uncertainty. A reduction of ambiguity will therefore contribute to reduce the total amount of true uncertainty in the overall situation. We therefore argue that an approach focusing specifically on ambiguity reduction in NPD projects is justified, as reduction of unwanted ambiguity can alleviate problems of true uncertainty.

In summary, we believe that ambiguity is a key contributor to much of the “fuzziness” experienced at the “Fuzzy Front End” of NPD. It is furthermore our belief that ambiguity is not limited to the front end, but may be present in the entire NPD process. We do, however, expect the highest likelihood of encountering ambiguity in its early phases.

Creating ambiguity

In Knight’s account of true uncertainty, his concern was primarily that of prediction. In an innovation process, the innovating company will typically be equally interested in shaping and controlling the outcomes (Wiltbank et al., 2006). This accords with our understanding of ambiguity as illustrated in Fig. 2. A cue (e.g. a market opportunity) can be interpreted by an innovating company, which then will shape a number of alternative interpretations of that cue and then use these as a way to create favourable outcomes. It must be noted, though, that this is a constructive
use of ambiguity, which is in accordance with previous authors’ accounts of useful strategies in settings of true uncertainty (Lane and Maxfield, 1996; Sarasvathy and Dew, 2005; Wiltbank et al., 2006). Also, Eisenberg (1984) has specifically argued for the usefulness of ambiguity in organisational communication in order to achieve strategic flexibility. These accounts describe a desirable ambiguity that fosters flexibility and innovation. However, by far all ambiguity occurring in NPD projects is proactively generated for such purposes. On the contrary, much of it is unintended, leading to excessive costs and time usage and therefore undesirable from a viewpoint of operational efficiency. Innovators therefore need to know both when to generate or sustain useful ambiguity as well as understand how to efficiently reduce undesirable ambiguity.

Reducing ambiguity

Weick has contended that the reduction of equivocality is the very reason for organising. He defined organising as a “grammar” for reducing equivocality, a grammar in the sense that it is a systematic account of some rules and conventions by which an organisation operates (Weick, 1979). Some years later, he explored these rules and conventions even further in his account of sensemaking, where he described reduction of ambiguity as one of its components. Sensemaking, he argued, is based on “paradigms”, or vocabularies of work, which in occupational communities refer to standard operating procedures, shared definitions of the environment, and the agreed-upon system of power and authority (Weick, 1995).

Dougherty (1992) showed that different “departmental thought worlds” — i.e. systems of common procedures, judgements and methods — exist in product-innovation processes and that members of these thought worlds produce different interpretations of development priorities and tasks. Dougherty suggested collaboration mechanisms to unify these thought worlds and thereby reduce the divergence of interpretations.

Reduction of ambiguity has also been addressed by Daft and Lengel (1986), who described a number of “structural characteristics” by which ambiguity can be effectively reduced in organisational communication. Specifically, they argued for using rich communication media such as group meetings and face-to-face contact to reduce ambiguity by enabling the organisational actors to overcome their different frames of reference.

As we see, the terms “horizon of understanding” used in hermeneutics theory, “paradigms” used by Weick (1995), “thought worlds” used by Dougherty (1992) and “frames of reference” used by Daft and Lengel (1986) align as common terms for the bases from which interpretations develop. The authors agree that ambiguity is reduced when the actors share these bases, but they do not explain the process by which ambiguity is reduced.
Although there is little research specifically addressing the theme of ambiguity in NPD, previous research has addressed uncertainty and uncertainty reduction in NPD. For example, Eisenhardt and Tabrizi (1995) have argued that NPD projects benefit from iterations and tests because frequent iterations build an understanding of the product, and an extensive testing gives frequent evaluations of the current design and accelerates understanding and re-conceptualisation of the product. Their arguments for iteration and testing thus allude to learning, understanding and conceptualisation, and as such the measures can be expected to relate to the reduction of ambiguity rather than to the reduction of uncertainty by our above definitions of the terms. We may therefore expect testing and feedback during NPD projects to have roles in the ambiguity-reduction process.

Interpretations, hermeneutics, hypotheses and hypothesis testing

Since ambiguity arises when a cue is assigned diverging interpretations, it is logical to direct our attention to theories of interpretation to gain understanding of ambiguity reduction. Hermeneutics constitutes one body of such theories. A central term in hermeneutics is the “hermeneutic circle”, where in the search for meaning of a text, an action or a set of ideas, etc. the interpretation of a part requires a prior understanding of the whole to which the part belongs, and the interpretation of a whole requires a prior understanding of its parts (Mautner, 2000). According to Føllesdal (1994), the hermeneutic circle can also be seen as a special case of the hypothetical-deductive method (HDM), where an interpretation is considered as a hypothesis and each loop of the circle represents a test of the hypothesis resulting in rejection or strengthening. In our conceptual model in Fig. 1, we have therefore indicated that each interpretation can also be regarded as a hypothesis. According to post-modernist critique, the hermeneutic circle cannot reach final closure as to concluding on the definitive meaning of a cue. Therefore, the hermeneutic circle is often rather described as an ongoing spiral. The spiral does not end, in accordance with Popper’s argument that a hypothesis can never be fully verified; it can merely be refuted or corroborated as a result of withstanding refutation (Popper, 1959; Popper, 1963). The upward move on the spiral represents a move towards reduced ambiguity through test, rejection and refinement of competing interpretations, or in other words: towards increased understanding with more refined and strengthened hypotheses.

Method

Research design

Our research design is a holistic multiple case-study design (Yin, 1994) with the NPD project as our unit of analysis. Our methodological approach involves building
middle-range theory (Merton, 1957) grounded in qualitative analysis of data from four case studies.

Sample selection

Each case was an NPD project, where we emphasized studying the early phase, because it is in the earliest phases that one is likeliest to encounter ambiguity. This, in turn, enabled us to collect data where we expected to find most of what we were studying (Eisenhardt, 1989). All cases were NPD projects in established companies in the medical-device industry. We believe that, for our purpose, cases from the medical-device industry were appropriate due to three characteristics of this industry. First, it has a high rate of NPD. Second, the business, engineering and clinical environments represent domains with widely different knowledge; hence, we expected a high potential for differing interpretations. Third, the industry is characterised by a high degree of structured and disciplined NPD methodology due to regulatory requirements; so, we expected that ambiguity experienced in these cases would be a natural component of the process rather than aberrance due to an absence of disciplined approaches.

We studied four cases: three in Norway and one in Denmark. The cases were selected to obtain a diverse sample of medical-device development projects, each being in the process of developing — or recently having developed — a new product. The case companies varied in size, age, product technology and in their approach to NPD as indicated in Table 1. To ensure anonymity, we have replaced all names with pseudonyms in the following case narratives and in all references to case data. We have given the case companies the names Alpha, Beta, Gamma and Delta.

Data collection

Our data, collected over three years, from March 2004 to August 2007, consist of 46 interviews, 7 hours of meeting observation, 913 pages of documentary data and 17 video files.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Alpha</th>
<th>Beta</th>
<th>Gamma</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company size (employees)</td>
<td>1200</td>
<td>100</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Year established</td>
<td>1940</td>
<td>1999</td>
<td>1984</td>
<td>1998</td>
</tr>
<tr>
<td>Product technology</td>
<td>Low-tech</td>
<td>Low-tech</td>
<td>High-tech</td>
<td>High-tech</td>
</tr>
<tr>
<td>Main focus in NPD project</td>
<td>Market need/ Business opportunity</td>
<td>Design</td>
<td>Technology</td>
<td>Lead-user need/technology</td>
</tr>
</tbody>
</table>
Cases Alpha and Gamma were studied throughout the duration of their NPD projects, and data were collected by three means; interviews, document review and observations. Cases Beta and Delta were studied retrospectively; hence, observations were not possible so data were collected solely by interviews and document reviews. There were elements of retrospective study also in the cases of Alpha and Gamma, since these ran over approximately two years and a few months often lapsed between interviews; hence, interviewees often had to recapitulate events. In every case, the NPD project manager was one of the interviewees. Additional interviewees included participants at board or top-management level and participants at middle-management level responsible for product development and marketing.

Each interview lasted for one hour on average. Since the research involved multiple sites, a format was employed for the interviews that provided a common framework and maintained cross-case comparability, but still permitted flexibility to exploit opportunities that presented themselves and allowed adaptation to each context and individual (Miles and Huberman, 1994). At the beginning of each interview, the interviewee was asked to provide a chronological description of the project as the interviewee had experienced it. The following supplementary questions were subsequently addressed when needed during the conversation:

- Why was this NPD project started? What is/was your role?
- What are/were the main problems or dilemmas you experience(d)?
- Does/Did the project run according to plan or are/were there deviances? If so, explain what happened.
- Whom do/did you primarily communicate with and how? What are/were their roles? How do/did you communicate?
- What decisions have been made (and need to be made) during this project?
- What do/did you experience as issues that need/needed clarification in this project?
- How was it clarified? Was something not clarified?

The first question though — that of providing a chronological description — would usually get the interviewee going on a narration who already answered many of the supplementary questions. In addition to the questions listed above, it was necessary to adapt to opportunities that presented themselves during the interview. As McCracken (1988) claims; “Once respondents have been brought within the sight of the topic, they must be allowed to go wherever they wish”. This was particularly true when dealing with informants as knowledgeable and articulate as our interviewees. The interviews were recorded digitally and transcribed in full.

In each case, a wide variety of documentary data was collected, including procedure documents, product documentation, project proposals and plans, project evaluations, internal and external presentations, press clippings, scientific articles
and clinician comments. Most of the documentary data was in paper format; some was also in video format. The video files contained product demonstration videos and clinical instruction videos.

Data were also collected by taking notes during non-participant observation during four project meetings: two in Alpha and two in Gamma.

**Data analysis**

The data that were analysed were the interview transcriptions, the documentary data and notes related to meeting observations and videos. The first step of our analysis was to build the conceptual framework shown in Fig. 1.

Guided by the conceptual model, we first searched the data for cues that were interpreted with two or more meanings, thereby identifying occurrences of ambiguity based on our definition of the term. We then coded these occurrences according to how the participants in the projects had responded to them. The findings fell into two categories: (1) responses that led to a reduction of ambiguity and (2) responses that led to a sustention or increase of ambiguity. This paper focuses on the first of these categories.

Responses that reduced ambiguity were further coded by constant comparison to data and to informing theory (Glaser and Strauss, 1967; Eisenhardt, 1989; Orton, 1997; Strauss and Corbin, 1998; Charmaz, 2006). The coding was a reflective process where empirical findings were conceptualised to a theoretical level based on the intimate closeness to the data that had been gained through the field work, as well as on our familiarity with relevant theory. Analysis was performed in cycles, each cycle consisting of the following steps: (1) identifying and comparing occurrences of ambiguity, (2) identifying and comparing actions that reduced ambiguity, (3) coding these actions and (4) refining the conceptual framework. The comparisons in steps 1 and 2 were performed within each case as well as across all the four cases. We repeated the cycles until no new findings occurred and our conceptual framework had developed into a model that was simple yet fit into our data. The software tool NVivo 7 was used to administer and document the data analysis.

**Trustworthiness**

To build trustworthiness of our analysis, the following measures were taken: internal validity, also referred to as *authenticity* in qualitative studies (Miles and Huberman, 1994), was built by a number of means. To limit interviewer bias on the site, care was taken to explain to the interviewee prior to the interview what the intention of our study was and how anonymity would be ensured. To limit “elite” bias, participants at multiple organisational levels were interviewed. Data were also triangulated from multiple sources, and interviewees were independently asked for specifics such as
dates, events and background information so that their accounts could be checked against each other and against documentary data. This measure also helped compensate for memory loss, a common source of error in retrospective studies. Finally, case descriptions were sent back to the key informants and confirmed for factual correctness (events, sequences, dependencies, persons involved, etc.).

Reliability, it may be argued, can be problematic in qualitative studies. Miles and Huberman (1994) have suggested the alternative terms dependability and auditability to address the underlying issue: whether the process of the study is consistent and stable across researchers. To build dependability and auditability, we have made every effort to document the analysis process so that the reader can follow the process and the researchers’ choices. The research process from case selection through data collection to data analysis is explicated above, and all raw data, memos and other documentation of the coding process are maintained in an NVivo 7 database. In addition to being two researchers partaking in the analysis and writing process, we have engaged in extensive colleague review including presentation and discussion of preliminary findings at international conferences and PhD workshops.

Case Descriptions

Case 1 at Alpha Medical

Alpha Medical develops, manufactures and markets products for emergency medical treatment and training. Alpha perceived two needs in the market: (1) When rescuers provide first aid to patients, a certain type of compression manoeuvres are often part of the treatment. According to Alpha’s clinical contacts in the market, these compressions are often performed in an inefficient manner, even by experienced rescuers, so a solution to improve such compressions seemed needed. (2) Organisations providing first-aid training had expressed a need to teach these compression manoeuvres more efficiently and also to shorten the duration of their courses. Towards these ends, Alpha pursued two product ideas. One was a device, called “the Snapper”, that could be placed on a patient during the compression manoeuvre. Each time the rescuer had performed the compression correctly, the Snapper would provide an audible feedback. The rescuer could use the device during a training course, stow the device in a first-aid kit, and then use it on a real patient when needed. The other product idea was a complete training system, called “First Aid 1-2-3”, to radically reduce the training time in first-aid courses. Managers pursuing the Snapper concept saw it as a natural component of the First Aid 1-2-3 system, a view that was not shared by the manager responsible for developing the First Aid 1-2-3 system.

Alpha experienced several other problems in the Snapper project. First, it proved difficult to find one product solution to optimally serve the needs of both the training
and the therapy applications. Second, Alpha had to provide an evidence of the product’s effectiveness in both settings to gain market acceptance. Third, within Alpha’s development staff, there were multiple interpretations of what the target market segment was. Was it the training market, the therapeutic market, professional rescuers or lay rescuers, the worldwide market, or more limited geographical segments? Also, Alpha had assumed that the Snapper idea would be appreciated by the first-aid user community. It turned out that the company instead had to make an effort to educate the market of the need for such a device. Three members of top management took detailed control of individual streams of the project, while the project manager, acting at a lower level of authority, struggled to maintain control and stay updated.

In the end, Alpha aborted development of the Snapper for both the training and the therapy applications. Two other products were launched instead — a totally different device for the therapy market, and First Aid 1-2-3, without the Snapper, for the training market.

Case 2 at Beta Medical

*Patient compliance* can be defined as “the degree to which patients adhere to a prescribed treatment scheme”. Beta Medical is a company offering product solutions for drug delivery to ensure patient compliance. A problem seen in this market is that patients suffering from chronic diseases often forget to take their medication or drop entirely out of their treatment schemes due to lack of motivation. Product solutions to improve patient compliance therefore needed to carry the necessary emotional appeal to this sensitive patient group. Beta’s customers were the pharmaceutical companies, who would sell their medications, which in this case would be pills packaged in “blister packs” (the foil sheets where each pill is inside a plastic bubble), bundled with Beta’s product. Beta had previously developed patient compliance devices for medications that were taken orally or through injections. It remained a challenge, though, to develop a similar, competitive product solution for treatments requiring pill medication.

For this, Beta developed several product ideas, two of which we here have called “Hi-tech” and “Lo-tech”. Idea Hi-tech was aimed at the specific market segment of clinical trials for new drugs and represented a product solution with advanced reporting, communication and display functions. Hi-tech was the top choice of Beta’s management because they considered the clinical trial segment as the most mature, facilitating a subsequent move into other market segments. Also, the pharmaceutical company that was the first potential customer — PillCo — was about to launch a new drug, and Beta therefore assumed that a product solution specifically suited for clinical trials would be appropriate. The other idea, Lo-tech, represented a user-friendly, low-cost product aimed at the consumer segment that the patient could
carry as a pill container with a simple, yet an effective reminder function. Beta’s management did not favour the Lo-tech concept as it was regarded as an overly “cheap” solution, not in accordance with the company’s high-end, high-quality reputation.

Still, Beta’s concept manager succeeded in convincing the R&D director to allow the Lo-tech development project to unofficially proceed. Three different stakeholder groups in the market were identified for the Lo-tech product idea: the patients, the doctors and the pharmaceutical companies. It was a major challenge for Beta to develop the Lo-tech idea into a product concept that had the necessary appeal to all three of these groups, that would be efficient in ensuring patient compliance, and that would still be cheap. Also, the concept manager chose to develop the product concept through a process that had never previously been tried at Beta. Throughout this concept development phase, there was a heavy emphasis on the visual design of the product. As it turned out, Lo-tech emerged as the product concept preferred by both PillCo and subsequent pharmaceutical customers. It was eventually launched commercially and earned two design awards.

Case 3 at Gamma Medical

Gamma Medical is a small company that develops, manufactures and markets ultrasound equipment for quality control in cardiac and vascular surgery. During cardiac bypass operations, one recommended procedure involves measuring the blood flow in the coronary arteries to verify the quality of blood flow before closing up the patient. The verification is done by assessing a combination of waveforms and numbers appearing on a monitor. The extent to which doctors actually perform this recommended control varies, however. Gamma Medical hatched the idea of providing the cardiac surgeon with an improved diagnostic tool in the form of a 2D colour image for a direct and easier clinical assessment of the blood-flow quality. But this required Gamma’s developing a new graphic user interface for use by a group of people (cardiac surgeons) unaccustomed to interpreting images as part of their medical procedures. Traditionally, such interpretation has fallen to cardiologists and anaesthetists. Introducing the innovation would therefore include some shifting of roles and expertise among the physicians, a potential area of conflict. Also, although the technique would improve quality control over the operation (a clear benefit to the patient), it might well be perceived as somewhat threatening to those surgeons who did not normally emphasize such quality control.

Being a small company, Gamma Medical needed to develop its technology in partnership with other companies. As such, it started the project with a heavy technology focus, devoting most of its attention in solving technology problems at the
cost of addressing the significant market challenges it would be facing. The project was studied by us up to the first clinical test of an early prototype.

Case 4 at Delta Medical

Delta Medical is a small company arising from a technological research environment. It came up with two promising product ideas:

- A product called the “LapDop”, which would provide surgeons with ultrasound Doppler guidance during laparoscopic surgery.
- A product called “BrainSound”, which would provide surgeons with ultrasound guidance during brain surgery.

LapDop became the subject of our case study. Laparoscopic surgery, often called “keyhole surgery”, is a technique where the surgeon operates through tiny incisions in a patient’s skin. A rod fitted with a light source and a camera lens is introduced through one incision, and operating instruments are introduced through the other incisions. The operation is performed by the surgeon while watching the image on a television monitor. The advantages of laparoscopic surgery are significant: less discomfort and quicker recovery for the patient. However, the optical technique used during the operation cannot detect blood vessels under the tissue surface, so there is a risk that these may accidentally be cut during the procedure. Delta’s solution to that possibility was to develop a product — the LapDop — using a sheath with an ultrasound probe attached to the operating instrument, enabling it to detect hidden blood vessels through sound feedback.

Delta conducted several clinical trials of LapDop to test and document its functionality and clinical applicability. The product concept and prototype was developed in close cooperation with a leading laparoscopic surgeon, but still the reception in the market was not as enthusiastic as Delta had hoped for. Clinicians held a variety of objections against the LapDop, mainly related to the price of the device, but Delta suspected that much of the scepticism stemmed from experienced surgeons who believed their knowledge of anatomy was sufficient guarantee against accidents and were unwilling to admit the need for a device that provided improved quality control. A further complication was that the users (the clinicians) were not necessarily the potential customers of the product, these would mainly be the hospitals’ purchasing officers. Being a small company with limited resources, Delta also faced problems trying to push two products to market simultaneously. Though both were based on ultrasound technology, they differed widely in terms of both target market and business model. Delta’s investors turned out to be more interested in pursuing the “BrainSound”, so early in 2003 Delta’s board decided to give it top priority. Delta made a final, but unsuccessful attempt to commercialise LapDop
by sub-licensing it to other medical-device suppliers. The project was, therefore, finally shelved in early 2006. A device of similar functionality has meanwhile been developed by a competitor in Japan.

Results from Analysis

Our analysis, based on our conceptual model and performed as described in the Methodology section, yielded the following analytic categories:

Cues

Our analysis revealed a number of cues that fit our conceptual model. They fell into four groups that pertained either to the product, the market, the NPD process or the organisational resources. For example, in the Beta case, the participants were faced with the cue “a product to ensure patient compliance”. Interpreting this cue resulted in the two interpretations of what the product should be like (Hi-tech versus Lo-tech). In the same case, the clinical trial segment and the consumer segment were two interpretations of the cue “the patient-compliance market”.

Assumptions

A participant in a case would interpret a cue based on whatever assumptions he or she held. In our data, the assumptions were found to fall into four categories. First were assumptions about the product. Participants in each case held varying assumptions about product efficiency, availability of technology, reliability of technology, production cost and appropriateness of technology to meet market needs. Second were assumptions about the market. Different participants would hold varying assumptions about user and other stakeholder needs, motivations and attitudes, about how the product would be used, about an acceptable price for the product, about achievable sales volumes, about what would be realistic adoption and diffusion rates and assumptions about market barriers and whether and how they could be overcome. At Alpha, one such assumption was that users would appreciate a device that could be used both in training and therapy. At Beta, meanwhile, one such assumption was that the clinical trial segment was the most mature segment for the initial launch of a patient-compliance product. Third were assumptions about the NPD process. Participants in each case held underlying assumptions about the company’s ability to run an NPD project within the required cost and time frame and also about its adherence to standard operating procedures. At Gamma, one such assumption was that their suppliers would deliver according to plan. Fourth were assumptions about the organisation. For example, Gamma assumed it was able to develop the ultrasound imaging application, although imaging was a specific application of the technology it had little experience with.
Interpretations

When the cues described above were interpreted by participants based on their sets of assumptions, the process resulted in explicated interpretations related to the product, the market, the NPD process and the organisational resources. Our analysis revealed several such explicated interpretations. At Alpha, the Snapper and the First Aid 1-2-3 training system represented alternative interpretations of the cue “a product to improve First-Aid compressions”. There were also alternative interpretations of the cue “the market for the Snapper”. These included, for example, “the training segment”, “the therapy segment”, “professional rescuers” and “lay rescuers”. At Beta, examples of alternative interpretations of the cue “a product to ensure patient compliance” were the Hi-tech and Lo-tech product concepts, while alternative interpretations of the cue “the patient-compliance market” were “the clinical trial market” (for the Hi-tech concept) and “the consumer market” (for the Lo-tech concept). At Gamma, there were shifting interpretations of the cue “the project time schedule”, since its assumptions about their partners’ commitment had to be continually revised, resulting in a progress plan that was ambiguous. At Delta, meanwhile, the LapDop product itself represented a cue that was subject to a variety of interpretations — e.g. as useful, easy to use, cumbersome, time-saving, time-consuming, essential or unnecessary.

Responses to reduce ambiguity

We found two categories of responses to ambiguity that led to its reduction: testing the interpretations and testing the underlying assumptions.

Testing the interpretations

In this category, companies tested their interpretations according to the logic of the HDM. Each interpretation represented a hypothesis held within the company. Some of these hypotheses were tested directly. If the outcome of the test was positive, then the hypothesis was confirmed; if the outcome was negative, then the hypothesis had to be either rejected or revised.

A typical example of this was seen at Beta, where the company presented working models of the two product interpretations, Hi-tech and Lo-tech to PillCo, the first potential pharmaceutical customer. In a major surprise, the hypothesis represented by the Hi-tech interpretation, which was favoured by the top management, was rejected while the hypothesis represented by the Lo-tech interpretation, which had more the character of a skunk work, was confirmed. Alpha similarly tested prototypes of its First Aid 1-2-3 training system in a controlled field trial in cooperation with what would become the first major customer of the product. In this test, Alpha’s interpretation of the product concept was rejected, modified and re-tested in a series
of iterations, and the hypothesis representing the final interpretation was confirmed. Gamma and Delta also performed clinical tests of their product prototypes. These served as tests of the various product interpretations, and as such represented testing of hypotheses that were developed based on assumptions about the users’ needs and perceptions and assumptions about the technology.

**Testing underlying assumptions**

One interesting category of response to ambiguity that we found involved participants performing tests not directly aimed at testing their interpretations, but rather testing the assumptions underlying those interpretations. The company would proceed with an interpretation if its underlying assumptions were tested and confirmed. If, however, one or more important assumptions were tested and rejected, then the interpretation itself was rejected too.

Alpha’s interpretation of the Snapper as a therapy device was based on a number of assumptions — about user needs and attitudes, price acceptance and product usage. To test these assumptions, Alpha convened a series of focus groups. When some of the assumptions were rejected, Alpha abandoned the interpretation of the Snapper as a therapy product. Alpha also embarked on a series of field experiments to test the assumptions underlying the two product interpretations for the training segment: the Snapper and the First Aid 1-2-3 training system. These tests confirmed its assumptions underlying the First Aid 1-2-3 interpretation of the product concept, but confuted its assumptions underlying the Snapper product interpretation. As a result, the Snapper was rejected as a product interpretation also for the training market. Beta, meanwhile, performed a limited number of targeted field visits before commencing development of the Lo-tech product concept. Through these visits, it tested, rejected, revised and confirmed a number of its staff’s assumptions about user needs, habits and motivation. Further development of the Lo-tech concept interpretations was based on these revised and confirmed assumptions. As for Gamma and Delta, they both performed a series of tests in their R&D labs where assumptions pertaining to technology, reliability, cost and performance were tested, rejected, revised and confirmed. Further development of their product interpretations reflected these revised and confirmed assumptions.

**A Model for Reduction of Ambiguity**

Based on the results from our analysis, we have developed our conceptual framework into a model explaining ambiguity reduction in NPD projects. Figure 3 represents the model.

A cue (at the left of the model) will be interpreted by the involved participants in an NPD project. In NPD processes, common cues will be the terms pertaining
to — or ideas of — the product, the market, the NPD process or the organisation’s resources. The act of interpreting such a cue will be based on the interpreting participants’ set of assumptions. Multiple sets of assumptions may be used by the involved participants to interpret the cue, but in the interest of simplicity our model illustrates just two such sets. The process of interpreting, based on such a set of assumptions, will lead to an interpretation of the cue. Multiple sets of assumptions to interpret the same cue result in multiple interpretations of that cue (which is to say, ambiguity). Again, only two interpretations are shown in our illustration for the sake of simplicity. Ambiguity is reduced by two approaches of the HDM. In the first approach, each interpretation can serve as a hypothesis that can be tested, resulting in its confirmation or rejection. The weakness in this approach is that if an interpretation is rejected, the underlying set of assumptions remains unchallenged, so it also remains a source for continued ambiguity. In the second approach, each assumption underlying an interpretation can serve as a sub-hypothesis that can be tested, resulting in confirmation or rejection. If the assumption is confirmed, then the interpretation relying on the assumption can be maintained. If it is rejected, then the basis of the interpretation relying on this assumption fails, so the interpretation, too, must be rejected. As in normal science, testing the underlying assumptions and thus reducing ambiguity at its source is clearly a more efficient approach for reducing ambiguity than testing only the interpretation based on these assumptions.

Fig. 3. Reduction of ambiguity.
An example: Beta Medical

The case of Beta Medical can be used to illustrate the model. Beta saw a product opportunity based on a need in the market for a product solution to ensure patient compliance to pill medication. This product opportunity became a cue subject to interpretation. They had multiple interpretations of what such a product could be, two of which were idea “Lo-Tech” (Interpretation 1 in Fig. 3) and idea “Hi-tech” (Interpretation 2 in Fig. 3).

Set 1 of assumptions in the model represents the set of assumptions underlying the Lo-tech interpretation. One of the first product concepts that were defined as the Lo-Tech interpretation (Interpretation 1) was a circular product model, based on the assumption that the pharmaceutical companies could start manufacturing circular blister cards rather than the square ones currently used. This assumption was tested by discussing with PillCo, who rejected the assumption. Changing from square to circular blister cards would require prohibitively heavy investments in replacing expensive manufacturing machinery. Beta therefore had to reject their Interpretation 1 (circular product model) and revise it. The revised Interpretation 1 was a Lo-tech concept based on square blister cards. There was a range of further assumptions underlying the Lo-tech interpretation, for example, about patient needs, habits, preferences and emotions and about the doctors’ needs for patient follow-up and treatment efficiency. Some of these assumptions were tested in a limited user survey during the concept development phase and either confirmed or rejected, with the result that Interpretation 1 was revised. Interpretation 1 was finally tested when the resulting Lo-tech product concept was presented to PillCo and confirmed.

Meanwhile, another development team was working on the Hi-Tech concept (Interpretation 2). There were a range of assumptions underlying this interpretation as well, one of which was the assumption that since PillCo was about to launch a new drug, they would primarily be interested in a device with functionality suited for clinical trials. This assumption was, however, not tested at an early stage and a Hi-tech product concept was developed as Interpretation 2 on this basis. Interpretation 2 was tested when the Hi-tech product concept was presented together with the Lo-tech concept to PillCo. PillCo rejected the Hi-tech concept, but this rejection in itself was not sufficient to clarify in what way the concept was at fault. However, it became clear from the following discussions that functionality for clinical trials was not as important to PillCo as Beta had assumed. Had Beta tested this assumption earlier, they would have been able to reject their interpretation of the Hi-tech concept — thus reducing ambiguity — earlier in the NPD process and save the costs of developing that specific concept further. Beta’s process ended up in the Lo-tech concept being the only interpretation that survived the final hypothesis test.
Our analysis and model show that companies can reduce ambiguity in NPD projects by applying the logic of the HDM. Ambiguity is reduced through the HDM not just by testing alternative interpretations but also by testing the assumptions underlying those interpretations held by the interpreting participants. Our findings accord with the theoretical argument presented by Duhem and Quine on the problem of falsification in the HDM (Chalmers, 2004). Duhem and Quine argue that when one attempts to test a hypothesis, one needs to be mindful that the hypothesis in practice will rely on numerous assumptions or sub-hypotheses. Thus, if the test we perform results in data that do not accord with the theory we are testing, then all we can conclude is that at least one of the underlying premises is false. We cannot, however, identify what particular thing is at fault; it may be the hypothesis being tested or it may be one or more of the underlying assumptions or sub-hypotheses. Transferring the argument to NPD practice, a test of a product prototype resulting in negative feedback would not necessarily provide an innovating company with enough knowledge to conclude which of the underlying assumptions behind the product idea is/are at fault, so ambiguity may not be sufficiently reduced. But by identifying and explicating the individual assumptions upon which the new product idea is based at an early stage of development, and then testing these assumptions individually by the HDM, the company can more efficiently limit competing product interpretations.

Our model does not imply that ambiguity is always reduced in NPD projects. Some researchers believe that the innovation process may not always be steadily moving towards lower ambiguity (Aldrich, 1999; Burgelman, 2002) and also that it may sometimes be useful to generate or sustain ambiguity (Eisenberg, 1984; Lane and Maxfield, 1996; Sarasvathy and Dew, 2005). As described previously in this paper, we did find such occurrences in our data where ambiguity had been sustained. We have presented our analysis of these findings and discuss the beneficial use of ambiguity in NPD processes in a separate paper (Brun et al., forthcoming).

Our use of retrospective studies may have an effect on the authenticity (internal validity) of our study. As described in the Methodology section, we took measures to guard against memory failure. However, another possible source of error with such studies is retrospective rationality. We may expect that less ambiguity was revealed in the retrospectively studied cases than if they had been studied in real time. However, we finally do not know how much this may have affected the model resulting from our analysis.

A tactic to build external validity, also referred to as transferability in qualitative studies, is to present a sufficiently detailed account of the findings as to enable the reader to judge how they can be transferred to other contexts (Miles and...
Huberman, 1994). In this paper, we have made our best effort to do so and to describe the characteristics of our sample enough to permit comparisons. Since the model is based on an empirical sample of only four case studies though, we cannot conclude that it applies generally to NPD projects. The analytical categories that were identified (cues, assumptions, interpretations, tests of assumptions and tests of interpretations) were however found across all four cases. Also, these analytic categories are not specific to the limiting characteristics of our sample, i.e. established companies in the medical-device industry in Norway and Denmark. One can expect to find cues, assumptions and interpretations pertaining to product, market, NPD process and organisation, and actions to test these assumptions and interpretations, in NPD projects regardless of company size, age, industry segment and geographical location. We therefore believe that our model also has applicability outside the limitations of our study. Further research is needed, however, to determine the full extent of its applicability, e.g. across industries and companies with different geographical locations, sizes, ages and approaches to NPD.

**Conclusion**

In accordance with our research objective, we have explored and explained how ambiguity can be reduced in NPD projects. Ambiguity arises from multiple interpretations of a cue, and we have argued that each interpretation represents a hypothesis held by the interpreting project participant. Our analysis has shown that ambiguity can be reduced through application of the HDM, and we have discussed theoretical implications of this finding.

Our research has managerial implications in that the HDM is both simple and supposedly well understood among many practitioners. So, we believe our model can provide practitioners with an increased understanding of ambiguity and how it can be reduced in NPD projects, thus improving their ability to manage their NPD projects efficiently. In situations that are experienced as “fuzzy”, we recommend managers to first determine whether this is caused by unwanted ambiguity, i.e. multiple and conflicting interpretations, pertaining either to the product, the market, the NPD process or the organisation’s resources. If so, they should explicate these interpretations and their underlying assumptions as hypotheses and test them individually. Identifying and testing underlying assumptions at an early stage of the NPD project will provide the most efficient reduction of ambiguity.

We suggest further research to determine the model’s wider applicability beyond the limitations of our sample. Also, we suggest research to improve our understanding of contexts in which ambiguity is sustained rather than reduced.
Ambiguity Reduction in New Product Development Projects

References


