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User involvement competence for radical innovation

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Abstract

One important market related capability for firms which seek to develop radical innovations is the competence to involve the 'right' users at the 'right' time in the 'right' form. While former studies have identified a rather passive role of users in the radical innovation process, this paper focuses on the involvement of such users that are in the position to play an active role as inventors and (co)-developers. A multiple case study analysis was conducted in the field of medical technology. Five radical innovation projects within four firms were selected including medical robots and computer-assisted navigation systems. The case study analysis reveals that firms who closely interact with specific users benefit significantly for their radical innovation work. These users have a high motivation toward new solutions, are open to new technologies, possess diverse competencies, and are embedded into a very supportive environment.
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1. Introduction, literature review, and research objectives

In today's environment of rapid technological change firms cannot rely on incremental innovations alone. To sustain long-term competitiveness firms need to generate radical innovations as well. Such innovations typically incorporate completely new and highly complex technologies, shift market structures, and require user learning as they often induce significant behavior changes on side of the users (e.g. Urban et al., 1996). To develop radical innovations, firms depend on technological and market related capabilities. One important market related capability is the competence to involve the 'right' users at the 'right' time in the 'right form'. Firms need to know which users are capable to contribute in distinct phases of the radical innovation process and how to interact with them.

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Due to the high market uncertainties of radical innovations, firms have a high need to involve users as a source of market related knowledge. However, taking into account the characteristics of radical innovations, firms face severe challenges when involving users in the radical innovation process. Two potential barriers on side of the users account for this. First, cognitive limitations can hinder users to deliver valuable inputs (*barrier of not knowing*). Excessive demands o the cognitive level can arise due to the following reasons:

- In the idea generation phase users can be 'functionally fixed' to their current use context and therefore unable to develop radically new ideas (Birch and Rabinowitz, 1951; Adamson, 1952).
- It is difficult for users to evaluate concepts and prototypes of radical innovations as no reference products exist (Tauber, 1974; Schoormans et al., 1995; Veryzer, 1998b).
- Users might not be able to provide valuable inputs due to the high technological complexities involved.

Second, users might not be willing to contribute to radical innovation projects (*barrier of not wanting*). This lack of motivation can stem from high anticipated switching costs and from the fear that existing knowledge becomes obsolete (Sheth, 1981; Ram, 1987; Ram and Sheth, 1989).

These barriers on side of the users might in part explain why former studies have identified a passive role of users in the radical innovation process (Urban et al., 1996; Lynn et al., 1996; Veryzer, 1998a,b; O'Connor, 1998; McDermott, 1999; Leifer et al., 2000; O'Connor and Rice, 2001). In these studies the radical innovation process followed a common pattern. Large established manufacturing firms were the source of radical innovations. Engineers of these firms developed the ideas, technologies, and prototypes. Thus, the locus of invention and development was inside the manufacturing firms. Users were primarily involved at the prototype stage to gain market oriented evaluations and to assess the market potential of the prospective new products. Consequently, users were a passive residual actor in the radical innovation process.

The identified passive role of users in empirical studies of radical innovations seems to be in contrast to the research field of user-driven innovations. In this field users have been shown to be a major source of innovation (Von Hippel, 1988, 2005). A review of empirical studies reveals that some users are very active in the innovation process by playing the roles of inventors and (co)-developers. This phenomenon was proven in numerous areas such diverse as scientific instruments (Riggs and Von Hippel, 1994), CAD software (Urban and Von Hippel, 1988), pipe hanger hardware (Herstatt and Von Hippel, 1992), medical surgery equipment (Luethje, 2003), library information systems (Morrison et al., 2000), and sporting equipment (Luethje et al., 2005; Franke and Shah, 2003). However, when considering the radicalness of user-driven innovations the cited studies reveal that the new products have a rather low to medium degree of innovativeness. This observation might be explained by the specified barriers of users in the context of radical innovations.

Both, the identified passive role of users in previous studies on radical innovations and the observed degree of innovativeness of user-driven innovations raise several important research questions: (1) are users able to play the roles of inventors and/or (co)-developers in radical innovation projects at all? (2) if some users are indeed capable to fill out these roles, how can firms systematically identify these highly creative users? (3) how do firms need to interact with these users to benefit from their creative contributions?

An understanding of these questions is crucial for firms who seek to benefit from users in radical innovation projects beyond product evaluation and market assessment purposes. Gaining innovation inputs from external sources has been recognized as an important mechanism to enhance the innovative capability of firms (Chesbrough, 2003). If some users are indeed in the position to actively contribute to radical innovations, then firms need to establish a competence how to systematically identify these users and how to effectively and efficiently interact with them. Therefore, this competence is a crucial element of the radical innovation capability of a firm.

By studying the addressed research questions this paper combines the research field of radical innovations with the research field of user-driven innovations and provides insights for a user involvement competence for radical innovations from this combination. The paper contributes to innovation research in three important ways. First, a conceptual framework of a user involvement competence is developed. Second, by focusing on users as inventors and (co)-developers of radical innovations the paper provides a new perspective on the sources of radical innovations. Third, the paper sheds light on the question how firms can identify and involve those users that are in the position to provide creative contributions for radical innovation projects. In this context the paper complements former studies which analyzed users as a passive actor in market research endeavors for radical innovations.

The paper is organized as follows. In the next section, a conceptual framework for a user involvement competence is developed. In the third section, the applied methodology of the empirical study is outlined. The findings of the empirical study are presented in section four. The finding section is organized according to the conceptual framework of a user involvement competence. Finally, implications of the findings are discussed.

2. Conceptual framework of user involvement competence

To systematically involve users into the innovation process, firms need a special competence on the organizational level. Based on former literature a conceptual framework for such a competence is developed in this section. This framework serves as an analysis grid for the empirical study.

Conceptually, two dimensions of a user involvement competence can be distinguished. First, firms need to know which users are capable to provide valuable inputs in innovation projects (Gruner and Homburg, 2000; Von Hippel, 1986). Hence, the first dimension of the user involvement competence of an organization contains knowledge about critical user characteristics (subject dimension). Competence on the subject dimension allows firms a segmentation of capable users according to distinct activities in the innovation process. In this context a clear understanding of critical user characteristics enhances the effectiveness of the search for valuable users.

Second, the firm needs to know what interaction patterns with users are appropriate in innovation projects (Kaulio, 1998; Gruner and Homburg, 2000). A review of the literature reveals that this dimension contains variables like the personal level of interaction, the number of users, the temporary extend of interaction, and the network competence of the user interaction personnel (interaction dimension).

It is argued that the outlined dimensions of a user involvement competence need to be differentiated according to different phases of the new product development process. Different phases contain different activities and task requirements. Therefore, the type of capable users and appropriate interaction patterns might differ in distinct phases. In this paper three generic phases are distinguished: idea generation, development, and testing. This phase classification was selected as the three phases differ significantly according to their associated activities and task requirements. The conceptual framework is outlined in Fig. 1.

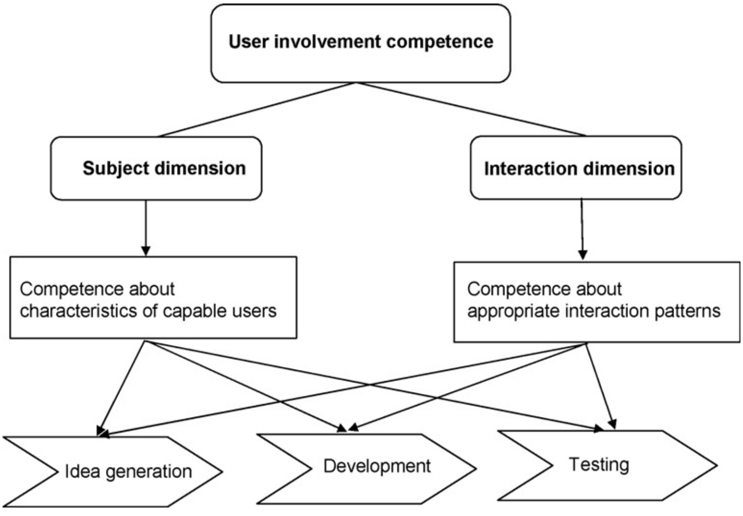

Fig. 1. Conceptual framework of user involvement competence.

With respect to the *subject dimension*, several approaches have been put forward to more systematically address customer needs in the innovation process (Leonard and Rayport, 1997; Kaulio, 1998; Geschka and Herstatt, 1999). One of the most prominent approaches is the *lead user* method which has gained considerable attention as a mechanism to leverage users for innovation projects. The lead user methodology aims to identify and involve progressive users into the idea generation and development phase. Lead users differ from ordinary users with respect to two characteristics. First, lead users face needs months or years before the bulk of the marketplace encounters them. Second, lead users benefit significantly by obtaining a solution to those needs and, therefore, are highly motivated to engage in the new product development process (Von Hippel, 1986; Urban and Von Hippel, 1988).

The question, however, remains whether the lead user approach is suitable for the development of truly radical innovations. Does a firm that learned to systematically apply the lead user method already possess a user involvement competence for radical innovations? Notwithstanding the general value of the lead user approach, some doubts may be appropriate. Empirical studies reveal that the implementation of the lead user method has the potential to generate 'next generation products' (Herstatt and Von Hippel, 1992; Von Hippel et al., 2000; Olson and Bakke, 2001; Herstatt et al., 2002; Lilien et al., 2002). These products have a low to medium degree of innovativeness, but do not match the characteristics of truly radical innovations. Therefore, it remains unclear whether lead users are capable to develop completely different solutions that form the basis for radical innovations.

The *interaction dimension* addresses the competence of a firm to manage the interface to users in innovation projects. Firms that intend to benefit from user contributions in new product development need to establish appropriate 'bridging strategies' (Pfeffer and Salancik, 1978; Homburg, 2000). 'Bridging strategies' consist of interaction patterns between the focal firm and users. The competence about appropriate interaction patterns is critical for two reasons. First, the transfer of different types of user knowledge requires different forms of interaction. While explicit knowledge can be shared by language and written documents, the transfer of tacit user knowledge requires face-to-face interactions (Nonaka, 1994; Leonard and Sensiper, 1998; Von

Krogh et al., 2000). Second, cooperation with users in the new product development process causes considerable costs. Thereby, the costs of user involvement differ according to the applied interaction pattern. For example, the temporary integration of users in new product development teams causes significantly more costs than selective meetings.

To conceptualize the interaction dimension four variables were deduced from the literature. First, the *level of personal interaction* characterizes whether the firm knows on which personal level it needs to interact with users. It is proposed that in radical innovation projects firms need to interact with users on a face-to-face-basis. As radical innovations incorporate new and complex technologies information that is transferred between users and the focal company is in need of explanation. Insights from communication research show that face-to-face interactions are superior for transferring this type of information (McQuail, 1987; Frey et al., 2000). Hence, dialog-oriented interactions are supposed be more appropriate for projects with a high degree of innovativeness (Salomo et al., 2003).

Second, the *number of users* indicates the firm's knowledge about how many users need to be involved in different phases of radical innovation projects. One could argue that the number of involved users should decrease from idea generation to market introduction. This argument is based on the school of thought that uncertainty in radical innovation projects is high in the very early phases and is successively decreased by managerial activities along the new product development process (Ancona and Caldwell, 1987; Clark and Fujimoto, 1989; Cooper, 1990). According to resource dependence theory (Aldrich, 1976; Pfeffer and Salancik, 1978; Pfeffer, 1987) and information processing theory (Galbraith, 1973; Galbraith, 1987; Wolf, 2001) this school of thought implies that the number of involved users needs to be high in early phases and can be gradually decreased in subsequent phases. A counterargument can be made however. In this reasoning it is supposed that in early phases only a very small, exclusive circle of users is capable to provide valuable inputs for radical innovation projects. As the projects get closer to market introduction the number of users needs to be increased as more representative information about the target marked has to be collected.

Third, knowledge about the *temporary extent* specifies whether the firm is aware about the appropriate time frame of user involvement in radical innovation projects. In principal, firms can involve users selectively or permanently into the new product development process. What time frame is more appropriate for radical innovation projects? There are theoretical arguments for both alternatives. An argument for a selective interaction pattern is that users possess 'sticky information' with regard to their needs and solutions for those needs (Von Hippel, 1994, 1998). A transfer of 'sticky information' to manufacturers causes high costs. It is therefore economically more reasonable that users develop solutions by themselves and transfer these to the manufacturing firm. This pattern implies that manufacturing firms and users work separately and meet from time to time to exchange their solutions (selective interaction pattern). The counterargument claims that firms need to explore and learn the tacit knowledge of users to develop radical innovations (Leonard-Barton and Doyle, 1996; Mascitelli, 2000). Thereby, tacit knowledge of users is considered as a key source of radical innovations. For the transfer of tacit knowledge close interactions over a longer period of time (permanent interaction pattern) are required (Nonaka, 1994; Leonard and Sensiper, 1998; Madhavan and Grover, 1998).

Fourth, the *network competence of user interaction personnel* is considered as an important component of the interaction dimension of user involvement competence. User interaction personnel are primarily employees from R&D, marketing, or new business development. Network competence contains the social and professional competencies of those employees who cooperate with external partners. The network competence of the user interaction personnel can be improved by instruments of human resource management such as human resource selection, establishment of incentive systems, and training (Ritter, 1998, 1999; Ritter and Gemuenden, 2003).

3. Methodology

To study the addressed research questions, I conducted an explorative case study analysis in the field of medical technology. The approach of case study research was used due to the nature of the research questions as well as the relatively little knowledge available in the addressed research field (Yin, 1994; Gillham, 2000; Stake, 2000). The industry of medical technology was selected for two reasons. First, former empirical studies show that users play an important role for new product development in this industry (Shaw, 1985; Biemans, 1991; Luethje, 2003). If I observe no innovation activity of users in the case sample, I could conclude that this is an effect of the high degree of innovativeness rather than an industry effect. Second, a number of radical innovations have emerged just recently with new communication and information technologies finding their way into the operating room.

I chose concrete innovation projects as the unit of analysis and applied a multi-case-comparison methodology. For the selection of cases the following criteria were defined:

(1) To select truly radical innovations the comprehensive scale of Salomo (2003) with respect to the degree of innovativeness was applied. Four dimensions are distinguished in this scale: a market dimension, a technological dimension, an organizational dimension, and an external resource-fit dimension.
(2) To gain an in-depth understanding of users who are in the position to be inventors and/or (co)-developers of radical innovations and how companies need to cooperate with them, such cases were selected where preliminary interviews and medical publications indicated that users were the source of the radical innovations. To reflect these cases with a contrasting case, one case was selected where preliminary interviews and medical publications indicated that the manufacturing firm developed the radical innovation internally.

For the selection of truly radical innovations a two-stage-filtering process was applied. The first stage contained visits of those medical conferences which focused on the application of completely new technologies. In addition, medical journals were screened with respect to emerging new technologies in the operating room. The result of this stage was a sample of 20 innovations which roughly matched the characteristics of radical innovations. In the second stage interviews with users, industry experts, and manufacturers were conducted to systematically assess the degree of innovativeness of these innovations. Informants assessed the degree of innovativeness of the new products on a questionnaire. For this purpose a seven-point Likert scale of the degree of innovativeness was applied. This scale contains a market dimension, a technological dimension, an organizational dimension, and an external resource-fit dimension.

Only those innovations were selected which matched the characteristics of radical innovations by exhibiting a high degree of newness on all four dimensions. To control for memory bias of informants, only projects were selected which were introduced to the market recently. The result from this filtering process were five radical innovations whereby preliminary research indicated that in four cases users were the source of the innovations while in one case the manufacturing firm developed the innovation internally. The final sample includes a medical robot system, two computer-assisted navigation systems, a radically new X-ray system, and a radically new biocompatible implant. The corresponding manufacturing firms are two large established firms, one medium sized firm which has a strong reputation for innovation, and one spin-off of a large German research establishment.

Innovation success was evaluated on the technological and market dimension using a seven-point Likert scale. Market success was evaluated by the following indicators: goal achievement with respect to profits, competitive advantage, customer satisfaction, and customer acceptance. Technological success was assessed by asking whether the radical innovation met the technical requirements. While rather common in quantitative studies, Likert scales were applied in this qualitative study for a detailed assessment of the degree of innovativeness and innovation success.

Each firm was visited for several weeks to collect the required data. In-depth interviews on the basis of a semi-structured interview guideline were conducted with marketing, R&D, project leaders, executive officers, and users. In sum a total of 45 interviews were conducted. Each interview had the duration of 2–3 h. Any interview was recorded on tape and transliterated. In addition, archival data was used to gain quasi-objective data. In this context an analysis of the users' websites was conducted to assess contextual factors of users. An analysis of the users' curricula vitae (as far as available) was conducted to identify and validate potential cross-qualification profiles of users (e.g. technical background). Also, I conducted a publication analysis of users' publications to validate the users' contributions and roles in the radical innovation projects. Finally, internal reports of manufacturers were analyzed to validate data from interviews.

To code the collected data, a content analysis framework was applied (Neuendorf, 2002; Krippendorff, 2004). Therefore, a system of categories for user characteristics, user activities and corresponding roles, interaction patterns between users and manufacturing firms, and the impact of user involvement for the manufacturing firms was developed. The category systems were developed both deductively (based on existing theories and concepts) as well as inductively (based on the collected data). For example, the lead user concept, theories on creativity, and diffusion theory served as a basis for the deductive component of the subject dimension. The inductive component in turn reflects the explorative nature of the study. Each category was specified with several indicators (see Appendix A for selected coding tables). To control for informant bias which can occur due to different corporate functions or hierarchical levels of informants, only those statements were included into the analysis which had a high degree of agreement between informants. Furthermore, archival data was used to validate the informants' statements with more objective data. Table 1 provides an overview with regard to the selected radical innovation projects.

Table 1
Selected radical innovations

Case	Product description	Innovation success MS: market success, TS: technological success	Number of interviews
SPOCS	Computer-assisted navigation system for neurosurgery	MS: medium, TS: high	9
orthoPilot	Computer-assisted navigation system for orthopedics	MS: high, TS: high	10
URS	Robotic system for neurosurgery	MS: medium, TS: high	8
IMPLANT	Biocompatible implant	MS: high, TS: high	9
GCF	X-ray system based on grid-controlled fluoroscopy	MS: high, TS: high	9

By studying user activities, corresponding user characteristics, interaction patterns, network competence, and impact variables this research aims to explore critical components of a user involvement competence for radical innovations. In the next paragraph the findings of the empirical study are presented. The main focus is put on the subject dimension.

4. Findings

4.1. Importance of user involvement competence

The case study analysis reveals that manufacturing firms that involved capable users in distinct phases of the innovation process benefited significantly from the users' contributions. This result highlights the importance of a user involvement competence on firm-level for radical innovation projects. Table 2 summarizes the effects of users' contributions for the innovating firms.

In those cases in which users played the roles as inventors and (co)-developers, manufacturing firms who took over the users' ideas and solutions benefited the most. These firms not just gained ideas for radical innovations but also benefited from the users' active contributions in the development phase. In this context, the development activities of the inventive users impacted positively on development time and cost. The active development contributions of the inventive users led to substantial improvements of product quality. The knowledge that was generated by the testing activities of users enabled firms to increase the use friendliness of the radical innovations. Use friendliness in turn was an important factor for market acceptance and ultimately market success. Finally, the information provided by the inventive users led to an improvement of the firms' decisions. Based on the users' information the innovating firms selected the 'right' prototypes and set the 'right' priorities.

To sum up, the contributions of the inventive users implied a substantial positive impact for the manufacturing firms that later introduced the radical innovations into the market. This finding implies the recommendation for manufacturing firms to systematically leverage capable users for their radical innovation work. For this purpose firms need to understand the characteristics of these highly productive users (subject dimension).

4.2. Subject dimension of user involvement competence

As proposed in the conceptual framework, critical user characteristics were analyzed according to the three phases of idea generation, development, and testing, respectively. The

Table 2
Impact of user involvement for manufacturers

Impact	Case				
	SPOCS	ortho Pilot	URS	GCF	IMPLANT
Acquisition of idea for radical innovation	+	+	+		+
Impact on development time	−	−	−		−
Impact on development cost	−	−	−		−
Impact on product performance	+	+			+
Impact on use friendliness	+	+	+		+
Impact on decision quality	+	+	+		+
Impact on internal barriers				+	

Impact direction: (+) increase and (−) decrease.

identified characteristics can be leveraged by firms as a heuristic search grid for capable users in radical innovation projects.

4.2.1. Critical user characteristics in the idea generation phase

Knowledge about critical user characteristics in the idea generation phase can improve the systematic search process for highly creative users. By involving these users firms can enhance their creative capacity for radical innovations. The case study analysis provides first insights with respect to this aspect.

As was intended in the case selection process, users were the original inventors in four cases (SPOCS, orthopilot, URS, IMPLANT). This raises the question what motivated and enabled users to develop radically new ideas. At the beginning, all innovative users shared a major problem: they faced severe difficulties in their day-to-day work that could not be solved by conventional manufacturers' technology or existing medical equipment. For example, the neurosurgeons (cases URS and SPOCS) faced problems of carrying out extremely precise (sub-millimeter) work. This need could not be met by standard neurosurgical instruments.

The fact that our sample of innovative surgeons encountered the limits of conventional technologies motivated them to search for other, more workable solutions (*motivation induced by problem*). As is known from research on creativity, high problem pressure is a key source for creative activities (Csikszentmihalyi, 1988; Boden, 1994; Collins and Amabile, 1999). In addition to problem-induced motivation, all innovative surgeons were *professionals* in their field and thus had *in-depth knowledge within their domain* of surgery. Furthermore, they had *knowledge about the respective needs* to improve the surgical process. This type of knowledge was gained by extensive learning, experience, and experimentation and thus is difficult and costly to transfer to third parties. Von Hippel (1994, 1998) calls this knowledge 'sticky'. This type of knowledge served as a crucial basis for the search for solutions that met the specific medical needs.

The idea creation and concept generation processes of the innovative surgeons followed a common pattern in all four cases. The surgeons abstracted from their current use context by searching for appropriate technologies outside of the medical domain. Therefore, *openness to new technologies* was a key prerequisite characteristic that all innovative surgeons shared. Once the relevant technologies were recognized, the innovative surgeons transferred these potential technical solutions to their medical domain. They applied analogical reasoning which is considered a suitable mechanism for the generation of radically new ideas and concepts (Vosniadou, 1989; Holyoak and Thagard, 1995; Dahl and Moreau, 2002).

For example, the neurosurgeon in the URS case looked for solutions to prevent trembling of the neurosurgeon's hands and thus to realize precision in the sub-millimetre area. In his search for solutions, the neurosurgeon observed, for example, nuclear power plants. Employees in nuclear power plants need a transmitter between them and the fuel elements. This observation triggered the idea that a neurosurgeon could also use a transmitter between his/her hands and the patient to better control trembling. Following this analogy, he investigated closely various principles of kinematic solutions. Robotic systems are based on kinematics, consequently the concept of a medical robot arm for neurosurgery was born.

In addition to problem-induced motivation, openness, and prior knowledge, a number of enabling factors played a major role for the development of the radically new concepts. Taking a closer look at these enabling factors, two types of innovative users could be distinguished. The first type was embedded into a context with close *access to interdisciplinary know how*. These users were surgeons at university hospitals which were part of technical universities or which had access to departments of technical universities. This interdisciplinary context inspired the surgeons' creative thinking as state-of-the-art technologies could be experienced. According to the concept of 'absorptive capacity' (Cohen and Levinthal, 1990), access to interdisciplinary know how served to increase the creative capacity of these users. Another important contextual factor of this user type was the availability of *resources for research* (time, funds, human resources). These resources enabled the innovative surgeons to perceive technologies outside of the medical domain and to think about possible technology transfers.

The second type of innovative user did not have access to these supportive factors. However, this type exhibited a strong *intrinsic motivation*. In addition to high problem pressure, these surgeons regarded the search for radically new solutions as their hobby and spent a substantial amount of spare time on it. This finding is in line with research on creativity that highlights the importance of intrinsic motivation for highly creative activities (Csikszentmihalyi, 1988).

It is interesting to note that the inventive users in the case sample do not match with the classical lead user definition. Although the inventive users were highly motivated to search for new solutions they were no progressive users in the sense that they faced needs which the mass market encountered months or years later. The needs and problems that the inventive users had were commonly faced by all users in these medical domains. To clarify this argument I refer to the inventive neurosurgeons. These neurosurgeons did not face future needs as the need for extremely high precision is of concern for the entire community of neurosurgeons. However, the inventive users can be regarded as lead users in a different sense. As the inventive users anticipated completely new technologies which became the medical standard in many different medical applications, these users were lead users with respect to new technologies. The case study analysis reveals that these 'technology lead users' can be the source of radical innovations and therefore an important cooperation partner for manufacturing firms.

The case GCF is contrasting to the other four cases. In that case users did not develop the original idea. One explanation for this observation can be found in the nature and perceived implications of the idea. The idea of a grid controlled fluoroscopy (GCF) implies minimal pauses of X-ray exposure. With these pauses it was possible to reduce the X-ray dose rate dramatically. But the idea had one important disadvantage in the perception of user radiologists. They argued that the pauses would imply a loss in diagnostic pictures which in turn could lead to false diagnostics. Picture loss was regarded as a 'taboo' in this user community. The idea of GCF therefore had what can be called a 'prohibitive disadvantage' in the perception of users. This 'prohibitive disadvantage' was a barrier for creative thoughts of user radiologists with respect to a GCF technology. In the case of GCF an internal engineer of PHILIPS generated the idea instead. This engineer had to overcome substantial resistance on side of the users. Not until he was able to prove that the human eye is capable to substitute missing information in certain intervals between two X-ray pictures he obtained valuable inputs from user radiologists.

4.2.2. Critical user characteristics in the development phase

Competence about critical user characteristics in the development phase allows firms to more systematically identify users that are in the position to provide various development contributions for radical innovations. The case study analysis sheds light on the profile of such users. In four of five cases users played the role of developers or co-developers of the radical innovations. What profile of characteristics enabled users for these activities?

A case comparison of user characteristics and associated development contributions implies a swell model with separate layers. Each layer can be considered as a critical activity level whereby higher layers are associated with more ambitious and challenging contributions. The first layer consists of *passive development contributions in the user domain*. These contributions include the articulation of needs and/or problems and the evaluation of concepts and prototypes. Being the standard routine of ordinary users in incremental innovation projects, our analysis reveals that in RI projects even this type of contribution requires distinct user characteristics.

The cases show that users need a *motivation caused by a current problem*, by *openness to new technologies*, as well as by *imagination capabilities*. This finding can explain why so called opinion leaders are not necessarily suitable informants in RI projects. Opinion leaders might lack one of these three prerequisites. Particularly, openness to new technologies is not necessarily associated with opinion leaders as their status is often based on conventional technologies. In the URS and IMPLANT cases, opinion leaders were indeed opponents of the RI and were therefore incapable of validly evaluating the concepts and prototypes. Our observation confirms results from former empirical studies that show that opinion leaders are not necessarily capable of recognizing the benefit of RI in the prototype stage (Lynn et al., 1996; Salomo et al., 2003).

The next layer constitutes *active development contributions in the user domain*, contributions that involve the development of own solutions. The case studies reveal that users need an additional set of characteristics in order to perform well on this layer. First, users need to have a *high competence in their own domain*. In order to develop solutions for RI, one needs to have a profound understanding of the elements, the causes, and the effects of a certain domain. Second, users need to have *tolerance of ambiguity*. This characteristic means that users who actively engage in the development of RI must be able to handle a great deal of uncertainty regarding the final output and benefit of their development efforts. Third, users need to have *access to technological know how*. This resource is critical for providing immediate feedback to innovative users regarding the technological feasibility of their solutions.

Using an iterative process, the innovative user can leverage the feedback to improve the own solution (Thomke, 1998; Thomke and Von Hippel, 2002; Thomke, 2003). In the case orthoPilot, an innovative surgeon developed the biomechanical solution of the computer-assisted navigation system for orthopaedics. By having access to the technological knowledge computer science possessed by the co-developing engineer, the innovative surgeon was able to iteratively improve his biomechanical solution. Fourth, users need *resources for own research activities*. One explanation of why this contextual factor is critical at this layer is the high complexity of such a task. Users need to intensively deal with the specific subject at hand and thus they require intellectual free space and resources such as time, facilities, and funds. In summary, specific characteristics enable users to realize active development contributions in their own domain.

To reach the highest layer, *active development contributions in the technological domain*, users also need *technological competencies*. The case SPOCS illustrates that point. In this case, a team of innovative neurosurgeons developed not just the concept but also a first prototype of a computer-assisted navigation system for neurosurgery. This development was possible as, in combination, the surgeons possessed all the necessary complementary technological knowledge on mechanics, computer programming, and electronics. One surgeon was a professional watch maker before he embarked on his educational track for neurosurgery. He therefore had the technological know how with respect to mechanics. Another surgeon trained himself auto-didactically in computer programming until he had sufficient computer programming skills. A third team member had a strong background in electronics.

Obviously, users with a diverse set of technological capabilities (‘cross-qualification’) form an attractive group as development partners for RI. Our analysis reveals that users that are capable of performing on this highest layer of the swell model are the exception rather than the normal case. Mostly users focused their development activities on the user domain. One explanation for this

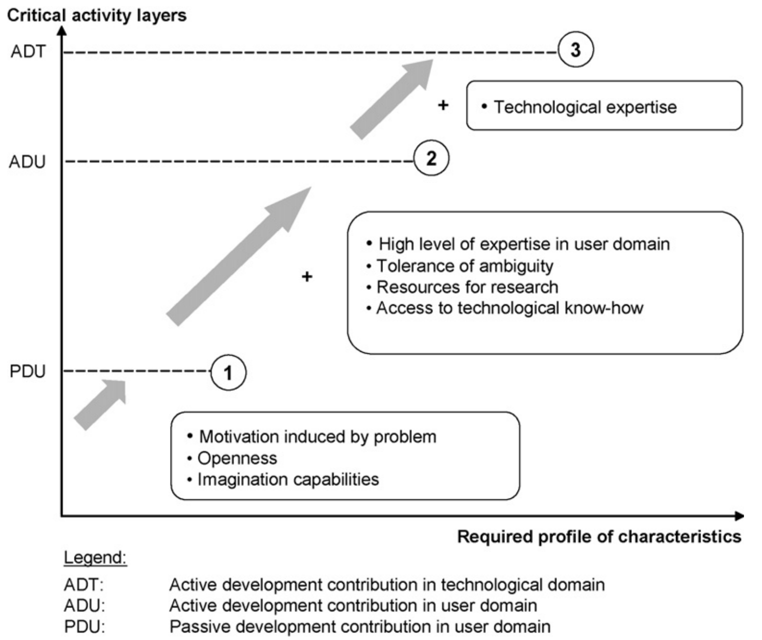

Fig. 2. Characteristics of users as (co)-developers.

observation is rooted in the nature of RI, particularly in a high technology field. The innovations profiled in our case studies incorporate new and highly complex technologies and a separate educational track is required in order to develop sufficient technological know how to master them. Most surgeons do not have the time and the 'absorptive capacity' to build up such technological competencies. The swell model with its three distinct layers is illustrated in Fig. 2.

The swell model constitutes a search grid for firms to identify users that are capable to deliver different kinds of development contributions in radical innovation projects.

4.2.3. Critical user characteristics in the testing phase

Besides the profile of highly creative users and of users as (co)-developers, firms need to know the characteristics of those users that are willing and capable to successfully test early versions of radical innovations. The case study analysis reveals that the capability of a firm to select suitable testing partners is crucial for the success of radical innovations.

The case comparison shows that the profile of users that were capable to successfully test prototypes of radical innovations differs significantly from the profile of users that failed. Firms that relied on 'conventional' characteristics for the selection of testing partners had a high failure rate of prototype tests. These characteristics that are at the focus of conventional marketing research methods included opinion leadership, representativeness, and high sales volume of the user. Obviously, the characteristic of opinion leadership is not a guarantee that this user is capable to successfully test prototypes of radical innovations. The same holds true for representative users or users that have a high sales importance for the innovating company.

What profile of characteristics do successful testers have? First, these users have a high '*innovation tolerance*'. This tolerance includes *openness for new technologies*, *willingness to take risks*, and *willingness to experiment*. The disposition of such an 'innovation tolerance' allows users to bear the uncertainties, risks and iterations that the testing process of radical innovations requires. In addition, a *geographical proximity* to the innovating company proved to be a critical contextual factor of successful prototype tests. As early versions of radical innovations mostly have several bugs, an intense face-to-face interaction between the innovating company and the user is essential in the testing phase. A high geographical proximity supports such an interaction pattern.

4.3. Interaction dimension of user involvement competence

Knowledge on the interaction dimension is crucial for firms that want to cooperate with users in radical innovation projects in an effective and efficient way. With regard to the *personal level of interaction* the case study analysis shows that face-to-face interactions are required. This finding can be explained by the nature of information that was transferred between users and manufacturing firms. This information was highly complex and therefore required additional explanations. In the studied radical innovation projects complex medical information with respect to surgical procedures and medical solutions was transferred to the manufacturer. The transfer of this type of knowledge requires face-to-face interactions at the user-R&D interface (Leonard-Barton and Doyle, 1996; Douthwaite et al., 2001; Ellis and Tyre, 2001).

How did the face-to-face interaction between the inventive users and manufacturing firms evolve in the early phases of new product development? In the idea generation phase, the inventive users contacted manufacturing firms and told them about their ideas. The users' intention was that manufacturing firms would take over their ideas and in turn deliver functional prototypes. However, the contacted manufacturers were not willing at that stage to commit themselves to the entire project management of the prospective radical innovations. Manufacturers were rather reluctant to get involved in the realization of the ideas. The reason was that the radical innovations did not meet the core competencies of the manufacturing firms. Particularly, the innovations did not fit with the technological knowledge base of the manufacturers. These firms would have had to build up completely new technological competencies in order to develop the radical innovations.

In addition, the manufacturers were deterred by the high technological and market uncertainties associated with the proposed innovations. To realize their ideas the inventive users therefore had to get actively involved in the development process. In the cases SPOCS, orthoPilot, and IMPLANT manufacturing firms did not actively get involved in the radical innovation process until first prototypes were developed. Was the reluctance of the firms the proper reaction? To answer this question, the success of the radical innovations needs to be assessed. The associated new products turned out to be successful both on the technological and on the market dimension. Consequently, manufacturers were reluctant to ideas and concepts that turned into successful innovations. However, this does not imply that the initial retention of manufacturing firms was not the proper reaction. Instead, the firms minimized the risk of their own investments by this passive strategy.

As the medical benefits of the radical innovations became more apparent by first functional prototypes, the firms changed towards an active strategy. From that moment the firms cooperated intensively with the inventive users and were able to acquire complete prototypes. The shift from a passive to a more active strategy enabled the manufacturing firms to introduce radical innovations in a relatively short time into the market. The case URS is different as the creative user and engineers from a large research establishment started a new venture which was based on the user's invention.

With respect to the *number of users* the cases reveal that only a very small number of users were active in the phases of idea generation and development (SPOCS, orthoPilot, URS, IMPLANT). An explanation for this observation is that only an exclusive circle of users is capable for creative activities in radical innovation projects. In this context, it is interesting to note that in three cases (SPOCS, orthoPilot, IMPLANT) the inventive users were supervising a small team of users consisting of assistant and senior surgeons. Therefore, the inventive users had access to human resources who assisted in the development of first prototypes. Obviously, the 'team factor' is an important contextual variable that supports active contributions of users for radical innovations. As the radical innovations passed into the testing phase, the number of active users increased. This increase was due to the need of manufacturers to test the relevance and acceptance of the radical innovations in a broader market segment.

Again, the case GCF is contrasting. In this case the manufacturing firm applied a large scale screening process of users. The goal was to identify users who were open to the GCF technology and therefore willing to conduct first prototype tests. Personal interviews with a large sample of users – particular at medical conferences – were conducted to assess their general attitude towards the GCF technology. As this new technology had a 'prohibitive disadvantage' in the perception of the radiologist community the identification of open-minded users turned out to be a challenging task. From a sample of around two hundred users the firm finally identified a small group of three users who were willing to test the new technology.

Fig. 3 illustrates the number of active and/or involved users in the three phases of the radical innovation process.

Looking at the *temporary extend of interactions*, the cases show that users and manufacturers cooperated in a selective interaction pattern. This was possible as users developed solutions on their own initiative. Users and manufacturers only met selectively for status meetings to report on

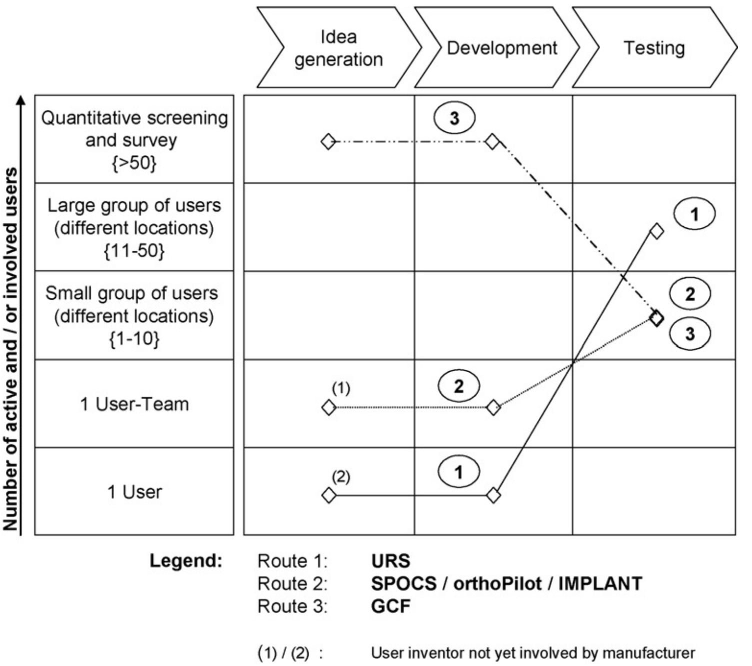

Fig. 3. Number of active and/or involved users.

the progress of their activities and solutions. The observed dynamic interaction pattern between users and manufacturing firms can be explained by the 'sticky information' concept. The inventive users had 'sticky information' in the form of tacit knowledge about their medical context. From a cost perspective, it was more efficient that manufacturers did not try to learn that kind of knowledge (e.g. by integrating these users in development teams). Rather users leveraged their 'sticky information' for the development of own solutions which were then handed over and explained to the manufacturing firms. The findings of the study therefore provide evidence that selective interactions between users and manufacturers are a more efficient and effective form of cooperation in the radical innovation process than the temporary integration of users in corporate development teams.

Finally, the case study analysis reveals that the *network competence of user interaction personnel* is crucial for the cooperation quality between manufacturers and users. Those manufacturing firms that invested in the social and professional competencies of employees that directly interact with users were able to manage the interface to users in a favorable way. These firms established special training seminars for R&D and marketing employees that were aimed to improve their competence to professionally interact with users. In addition, the motivation and skill set of employees to communicate effectively with users was applied as an explicit selection criteria for prospective user interaction personnel. Firms that did not invest in the network competence of user interaction personnel faced difficulties in the interaction with users.

In these cases user interaction personnel and users had severe communication problems. The reason was that user interaction personnel did not have sufficient competencies to understand the 'language' of users. In these cases the communication problems had a negative impact on the cooperation quality between the manufacturing firms and users. It is interesting to note that the manufacturing firms did not employ medical doctors as user interaction personnel. Conceptually, the employment of users who are responsible for the interface management to users outside of the firm seems to be a promising approach. Employed users understand the 'language' of external users and share the same 'mental models'. The manufacturing firms however emphasized disadvantages of this approach. They argued that employed medical doctors would not be well respected by doctors who practice. Surprisingly, 'doctors in practice' would prefer to cooperate with engineers if these engineers possess a basic understanding about the medical context. Once employed by a manufacturing firm, it is obviously difficult for medical doctors to maintain close ties to the community of practicing doctors.

5. Discussion and conclusions

The findings have implications for the capability of a firm to more systematically leverage the potential of users in the radical innovation process. With regard to the subject dimension of user involvement competence, the case study analysis provides first insights about the profile of users that are in the position to generate ideas, (co)-develop and successfully test prototypes for radical innovations. These users differ significantly from those user types that are typically involved in conventional marketing research. While conventional marketing research techniques are appropriate for incremental innovations they are of limited value in radical innovation projects. These innovations require a completely different marketing research approach (Lynn et al., 1996; O'Connor, 1998). Consequently, companies that work on radical innovations need to develop a completely different user involvement competence than companies that primarily generate incremental innovations.

Is the pure implementation of the lead user concept a suitable approach? With regard to this question, it is important to note that the inventive users in the observed cases do not meet the classical lead user definition. However, the inventive users in the case sample share some characteristics that are associated with lead users. First, the inventive users had a high motivation for the development of new solutions. Second, the inventive users in two cases were neurosurgeons which can be categorized as 'extreme users' as they faced the need for extremely high precision. It has been shown that lead users frequently appear among 'extreme users' (Von Hippel et al., 2000; Lilien et al., 2002; Herstatt, 2002). Hence, it is concluded that the inventive users have certain similarities with lead users in the classical sense. However, the empirical study in this paper reveals that additional characteristics are needed to contribute substantially to the development of radical innovations. Even though the inventive users do not meet the classical lead user criteria, they can be considered as lead users in a different sense. These inventive users recognized the relevance and benefit of new technologies far earlier than manufacturers and peer users. These new technologies became the medical standard in many different medical applications. Consequently, these inventive users can be regarded as 'technology lead users'. The identification of these 'technology lead users' is a crucial task for firms who seek to benefit from users as a source of radical innovations.

Would manufacturing firms be able to develop the inventive users' radically new ideas? This question, by nature, is difficult to answer. It needs to be taken into account however that the development of these ideas required a deep understanding of user needs and a creative compound with relevant technologies outside of the medical domain. The in-depth knowledge about user needs is tacit and therefore difficult to transfer to third parties (Von Hippel, 1994, 1998). Consequently, users have exclusive 'access' to this type of knowledge. This reasoning might explain why users and not manufacturing firms developed the radically new ideas.

With respect to a more systematic approach for user involvement in radical innovation projects, the identified characteristics of 'technology lead users' can be applied by manufacturing firms as a heuristic search grid. A search grid to identify these highly creative users is illustrated in Fig. 4.

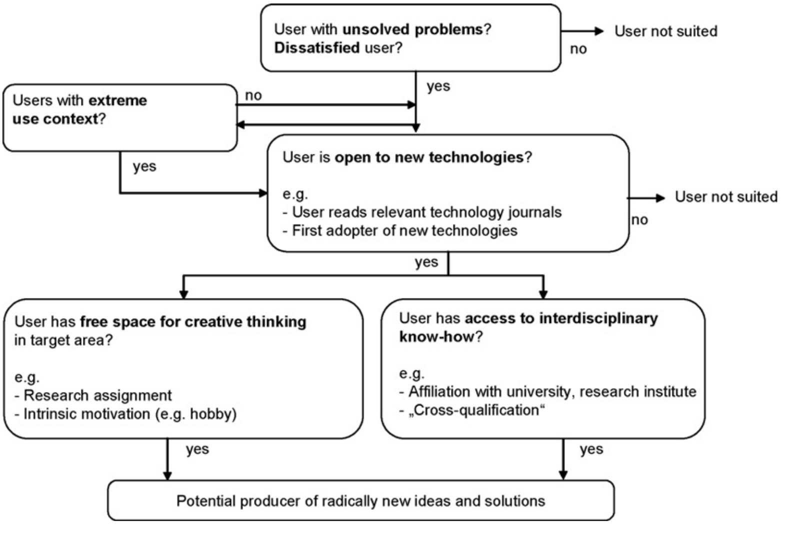

Fig. 4. Search grid for 'technology lead users'.

The identification of such creative users can increase the creative capacity of an organization as radically new ideas and solutions can be gained. Hence, one dimension of the organizational competence for radical innovation is the capability to identify this group of highly creative users. In similar form, the swell model can be leveraged as a heuristic search grid for the identification of such users that are capable to play the role of (co)-developers for radical innovations. Hereby, firms can accomplish a segmentation of capable users for the development phase of radical innovations. The swell model (Fig. 3) implies the thinking in 'user pyramids'. It is assumed that the number of users decreases with higher layers as higher layers are more challenging and require additional characteristics. Consequently, it is supposed that it is more difficult for companies to identify users on top of the pyramid (users capable for active development contribution in technological domain) as to identify users at the bottom of the pyramid (users capable for passive development contributions in the user domain).

As few users are capable of delivering substantial contributions for RI, manufacturing firms need to conduct the user selection process diligently. In this connection a pyramiding approach of market research was shown to be suitable for the identification of leading-edge expertise within a given population (Von Hippel et al., 2005). 'Pyramiding' means that the market researcher asks an informant within a defined population whether he or she knows someone who is highly knowledgeable about a specific field of expertise. Once this person is identified this person is asked whether he or she knows someone who is even more knowledgeable. This procedure is repeated until the top experts are identified.

The identified profile of successful and failed prototype testers serves as a heuristic to more systematically select suitable users for the testing phase. As becomes apparent from the study, the profile of capable users differs according to the phase of the radical innovation process. Consequently, firms need to cooperate with distinct users as the radical innovation project proceeds in the next phase. As the case sample shows only very few users were capable to deliver productive contributions for the radical innovations. Consequently, firms need to conduct the user selection process very diligently.

The empirical findings also provide first insights with regard to the interaction dimension of user involvement competence for radical innovations. Face-to-face interactions are needed to develop an understanding of the complex information that users transfer. An increasing number of involved users and selective interactions are an effective and efficient way to interact with users in radical innovation projects. The findings with regard to the network competence of user interaction personnel imply that firms need to invest in the social and professional skills of user interaction personnel to improve their interface management to users in radical innovation projects. This competence can be supported by human resource management instruments such as selection of motivated employees, establishment of incentive systems, and the enforcement of special training seminars. A high network competence of user interaction personnel enhances the cooperation quality between innovating companies and users.

Recapitulating, this study contributes to the development of a more systematic approach on firm-level to identify and integrate capable users in the radical innovation process. The study focused on the field of medical technology. Hence, further research in other industries is needed to explore whether the identified patterns can be generalized. The observed projects were successful ones. Future research could include failed radical innovation projects in which users contributed actively as inventors and/or (co)-developers. This research approach can provide insights how to discriminate users who develop ideas and prototypes of commercially attractive and commercially less attractive radical innovations.

It also should be taken into account that an explorative and therefore qualitative research approach was applied. Therefore, further research is needed to test the proposed concept of a user involvement competence for radical innovation on a more quantitative basis.

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Appendix A. Selected coding tables.

User characteristics (I)	Indicators	Examples from interview protocols/ archival data
Motivation induced by problem	Perceived problem	“We had the problem that patients would feel very uncomfortable with the implant after a while” (Informant: User/Case: IMPLANT)—Publication analysis
	Dissatisfaction with existing solutions	“The surgeons in pediatrics were very dissatisfied, because there were no adequate radiology systems for them.” (Informant: R&D/Case: GCF)—Publication analysis
Intrinsic motivation	Fun	“To me it was fun to work on my vision of the operating room 2015. This is nothing you do because someone tells you to do it. You do it because you enjoy it.” (Informant: User/Case: URS)
	Hobby	“The whole thing was a hobby for him. He spent a tremendous amount of his spare time to bring his vision and ideas to life.” (Informant: Marketing/Case URS)
Openness to new technologies	User deals with new technologies (e.g. by reading technical journals)	“I am constantly dealing with new technologies that might be relevant for my medical field. I study technical journals to keep me posted about what is going on with respect to new technologies.” (Informant: User/Case: IMPLANT)
	Openness to accept new technologies as solutions for the medical field	“Neurosurgeons are from their attitude much more open to new technologies as for example orthopedics . . . the reason is that they need to work with a precision in the submillimeter area and conventional technologies did not really meet this need.” (Informant: R&D/Case: SPOCS)

Appendix A (*Continued*)

User characteristics (I)	Indicators	Examples from interview protocols/ archival data
Technological competencies	Background in science or technical disciplines	"Prof. Reinhard was remarkable capable in the technical field. He had profound know-how in the field of mechanics as he took an education in watch making before starting a career in medicine" (Informant: R&D/ Case: SPOCS)—Background in science or technical discipline identified in the curriculum vitae of the user
	Software-programming skills	Dr. Horstmann has written the software programs for the device. He acquired these skills autodidactively." (Informant: R&D/Case: SPOCS)
Resources for research	Team	"This surgeon has an own team of surgeons who do research." (Informant: Marketing/Case: Implant)—Analysis of users' website
	Research laboratories	"Prof. Reinhard had own laboratories and technical equipment like milling machines." (Informant: R&D/Case: SPOCS)—Analysis of website of users
	Budget	We had own funds and raised funds for our innovation project." (Informant: User/Case: orthoPilot)—Analysis of project report "The innovative activities of the users in Basel was supported from Swiss public funds." (Informant: Marketing/Case: SPOCS)
	Time	"These users at university hospitals also have the time to work on innovative solutions. This is a clear difference to surgeons in ordinary hospitals." (Informant: Marketing/Case: IMPLANT)
Access to interdisciplinary/ technological know-how	Short communication distance to interdisciplinary expertise	"They also work interdisciplinary in this university hospital. There are several technical research institutes close by; this way there were different disciplines involved and they had short communication distance to communicate and exchange ideas." (Informant: R&D/ Case: IMPLANT)
	University hospital is embedded in a university of technology	"The advantage that this group of users is that they are embedded in the university of technology." (Informant: R&D/Case: IMPLANT)—Analysis of university and users' web site

Appendix A (*Continued*)

User characteristics (I)	Indicators	Examples from interview protocols/ archival data
	Departments of the university of technology are embedded in the university hospital	";; . . . and so the Lab for Robotics and Navigation was born inside the hospital, it was located in the department of the hospital." (Informant: User/Case: orthoPilot) -Analysis of university and users' web site
Independent development of idea [inventor role]	User develops idea without external assistance	"Dr. Urban has developed this idea. He had the idea right from his work in the operating room in his mind. (Informant: Marketing/Case: URS)—Publication analysis (publications of the user in medical journals)
Passive development contribution in user domain [(co)-developer role]	Definition of requirements	"The user in Munich has defined the profile of requirements for his specific medical application field." (Informant: R&D/Case: SPOCS)
	Information how to integrate the innovation into the use context	"The observations in the operating room were always very valuable. The surgeons showed us how to integrate the robot into the surgical process." (Informant: R&D/Case: URS))
Active development contribution in user domain (development of solutions in the medical domain) [(co)-developer role]	Development of the medical solution for the innovation	„Dr. Pickard developed the solution for the anatomical and biomechanical part. These were the medical foundations of the orthoPilot." (Informant: R&D/Case: orthoPilot))—Publication analysis (publications of the user in medical journals)
Active development contribution in technological domain (development of solutions in the technological domain) [(co)-developer role]	Development of components of the prototype/development of the complete prototype	"The surgeons in Basel developed the complete first prototype by themselves." (Informant: R&D/Case: SPOCS)—Publication analysis (publications of the users in medical journals)
	Computer programming	"This surgeon has developed the software for the navigation system." (Informant: R&D/Case: SPOCS)—Publication analysis (publications of the users in medical journals)

Note: The interview citations were translated from German into English.

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