Users as inventors and developers of radical innovation: An explorative case study analysis in the field of medical technology

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Abstract

Our study focuses on the question, whether users should be intensively involved in the innovation process of radical product innovations or better not – from the manufacturer's perspective. Radical innovations incorporate new technologies, shift market structures, require intensive user learning and induce significant behavior changes. Due to these specifics the question arises, whether users play a productive role in the innovation process of radical innovations at all, or if their contributions might even be counterproductive. To gain a better understanding for the users' role in radical innovation and to develop a differentiated view of their contributions, we have studied three dimensions of user involvement were studied: (1) Which characteristics enable users to contribute to the innovation process? (2) How do manufacturers need to interact with users to benefit from their contributions? (3) How does user involvement impact on the manufacturer? We focused our study on the early phases of the innovation process. Two phases were distinquished for the analysis of these questions: Idea generation and development. This distinction allows us to analyse the role of users within separate phases of the innovation process. Based on relevant theories and empirical work a set of propositions was formulated for each dimension. To study the addressed research questions, an explorative case study analysis was conducted in the field of medical technology. Five radical innovation projects were selected including medical robots, navigation systems, and biocompatible implants. In-depth interviews were conducted with marketing, R&D, project leaders, CEO's, and users. A content analysis framework was applied to systematically analyse the collected data.
The case studies reveal that users with a unique set of characteristics (motivation, competencies, contextual factors) were able to deliver major contributions in all three phases of the radical innovation projects. In four cases users turned out to be the original inventor of the radical innovations. Particularly users that work under extreme conditions (e.g. neurosurgeons) prooved to be a valuable source for radically new ideas. Furthermore the cases show that the innovative users took over classical functions of manufacturers in the development process. For example the innovative users identified relevant experts and manufacturers that were required to transform their ideas into prototypes and products. These users therefore took over the networking function. some users were able to actively contribute to the development of first prototypes. A unique set of characteristics enabled users to do so. With regard to appropriate patterns of interaction between users and manufacturers the analysis reveals that face-to-face-interactions are required. This is due to the nature of information that is transferred. The information provided by users and by manufacturers is highly complex. Therefore explanations and visualisations are needed to gain an understanding on either side. In addition the analysis shows that it seems to be appropriate to interact with a small, well selected number of users in early phases and to increase the number of involved users as the project gets closer to market introduction. In four cases specific users contributed significantly to NPD success. Based on the results of the study, the recommendation for manufacturers is to leverage the knowledge of users with certain characteristics for radical innovation projects. The results of our study form the basis of a market research concept for radical innovations.

1. Introduction

In todays environment of rapid technological change companies can not rely on incremental innovations alone. To sustain long-term competitiveness companies need to develop radical innovations as well. Such innovations typically incorporate new and highly complex technologies, shift market structures, require user learning as they often induce significant behavior changes on side of the users. Examples of radical innovations are the first mobile telephones, the internet with its first applications, fuell cell driven automobiles as well as medical robots. To systematically develop radical innovations, companies need to involve the proper actors.

One such important actor in the development process of new products is the user. Empirical studies reveal that users sometimes play the role of innovators in new product development (Herstatt and von Hippel 1992; Lüthje 2003; Lüthje et al. 2003; Urban and von Hippel 1988). Hereby users are the actual inventors of innovations and dominate the innovation process. This observation challenged the *manufacturer active paradigm* which assumes that manufacturers dominate all activities from idea generation to market introduction. Based on the empircal evidence a separate paradigm was proposed: the *user active paradigm* (von Hippel 1979; von Hippel 1978). However, if the degree of innovativeness is considered the studies reveal that user innovations are of rather incremental nature. Therefore it is unknown, wether users can be innovators for radical innovations as well. Taking into account the characteristics of radical innovations, an active role of users is impeded by two major barriers. First, users might not be able to play an active role due to cognitive limitations (barrier of not knowing). Users can be functionally fixed to their current use context and therefore unable to develop radically new ideas (von Hippel 1986). Due to the high degree of technological newness, it is difficult for users to validly evaluate concepts and prototypes of radical innovations as no reference products exist (Urban et al. 1996; Veryzer 1998). Due to the high degree of technological complexity users are possibly not able to actively contribute to the development of radical innovations. Second, users might not be willing to actively contribute to the development of radical innovation (barrier of not wanting). This lack of motivation can steem from high anticipated switching costs as well as from the fear that existing knowledge becomes obsolete (Ram and Sheth 1989). Due to these severe barriers the question arises wether users play a productive or even a counterproductive role in the innovation process of radical innovations. If users can indeed play a productive role, we would like to better understand which profile or characteristics such users have. This would allow an ex-ante segmentation and systematic search for such users before an innovation project might be started. In addition, it would allow to better understand and hence structure the way, how a manufacturer needs to interact with users to leverage from their contributions.

To shed light on the role of users for radical innovation we conducted an empirical analysis in the field of medical technology. We found that users with a distinct set of characteristics can be innovators for radical innovations. These users have a high motivation toward new solutions, posses diverse competencies and are embedded into a very supportive context. In four of our five cases the contributions of the innovative users had a positive impact on the manufacturer.

The paper is organized as follows. In the next paragraph we introduce theoretical perspectives relevant for the addressed research questions. In the third section we introduce methodology and findings of our empircal study. Finally, we discuss implications of the findings.

2. Theoretical perspective

Which role do users play in the innovation process of radical innovations? To analyse that question a framework for distinct user roles needs to be developed. Such a framework can be based on two dimensions. First, the *activity level dimension* describes wether users contribute rather actively or passively to new product development. While active contributions contain the development of own solutions to recognized problems, users contribute passively by providing innovation-related information. Examples for active contributions are the development of own ideas and prototypes. Users hereby take over the roles of inventors and developers respectively. Examples for passive contributions are the pure articulation of problems with existing products, requirements, and evaluations. Such contributions are associated with the roles of a claim formulator and an evaluator respectively. Second, the *domain dimension* describes in which area users contribute. Two domains can be distinguished: the user domain and the technological domain. While activities in the user domain require only use-related knowledge, activities in the technological domain call for technological competencies as well.

To explore the role of users for radical innovations from a theoretical perspective, we first consider the activity level dimension. To actively contribute to radical innovations users need to develop creativity and activities that strongly depart from their current use contexts and conventional solutions. The question is wether users are able to do so. One theory that is fruitful for the analysis of this question is the *theory of social perception*. This theory claims that perception is controlled by a system of hypotheses that individuals develop by experience (Bruner 1957; Bruner and Postman 1951). By using products repeatedly users form a set of hypotheses with regard to their use context. This set of hypotheses controlls what users perceive and therefore limits their mental ability to abstract from the current use context in favor of completely different solutions. Due to their use experience users can underly a *functional fixedness* (Allen and Marquis 1964; Birch and Rabinowitz 1951) which is a vessel for truly creative thinking. The hypothesis theory of perception therefore implies a rather pessimistic view on active contributions of ordinary users for radical innovations. If not ordinary users than so called *lead users* are possibly able to develop solutions for radical innovations. 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 innovation process (Urban and von Hippel 1988; von Hippel 1986). Empirical studies reveal that lead users indeed exist in several industries and that they are able to develop novel solutions which lead to “next generation products” (Herstatt and von Hippel 1992; Olson and Bakke 2001; Urban and von Hippel 1988). These products have a low to medium degree of innovativeness, but do not match the characteristics of radical innovations. Wether lead users are capable to develop completely different solutions that form the basis for radical innovations therefore remains unclear. Our theoretical considerations lead to the proposition that users are not able to develop own solutions for radical innovations. This proposition is confirmed by empircal studies that reveal that user innovations are of rather incremental nature (Lüthje 2003; Lüthje et al. 2003; Shah 2000).

With regard to the domain dimension the concept of *bounded rationality* provides a useful theoretical framework (Simon 1957; Simon 1996). The concept of bounded rationality suggests that the rationality of individuals can – in contrast to neoclassical theory- not be perfect. The reason is that the cognitive capacities of individuals are limited and that individuals therefore are not capable to fully cope with the complexity of their environment. One strategy to cope with this situation is to focus one’s activities to specific domains. By concentrating on specific domains, individuals can increase their level of rationality as the complexity of their environment is reduced. This strategy is therefore one of complexity reduction (Dequech 2001; Gigerenzer 2001; Gigerenzer and Selten 2001). The concept of bounded rationality implies the proposition that users will focus their activities in radical innovation projects on the user domain. To contribute within the technological domain users would need to establish technological competencies. As radical innovations are based on new and highly complex technologies the development of these competencies requires a separate education. The strategy of complexity reduction therefore calls for a focusing on the user domain.

Taking together, our theoretical considerations imply the proposition that the innovation process of radical innovations follows the *manufacturer active paradigm*. As radical innovations incorporate new and complex technologies, we expect that only manufacturers are capable to develop those technologies and to transform these into really new products. Therefore we suppose that manufacturers dominate the entire innovation process. Consequently, we assume that users play a rather passive role in the innovation process of radical innovations. We propose that users are involved by manufactuerers only punctually as claim formulators and evaluators.

The interaction dimension addresses the management of the interface betweeen users and manufacturers in innovation projects. We distinguish three variables of this interface managment from the perspective of a manufacturing firm. First, the *level of personal interaction* characterizes wether users and manufacturers interact face-to-face or rather nonpersonal.

Examples of the first are face-to-face interviews with users, examples of the latter are survey studies with questionaires. We propose that in radical innovation projects manufacturers 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 manufacturers is in need of explanation. Insights from communication research reveal that face-to-face interactions are superior for transferring this type of information (McQuail 1987). Second the *number of users* indicates how many users are involved along the innovation process. We propose that in early phases only a very small, exclusive circle of users is capable to provide valuable input to radical innovation projects. As the project gets closer to market introduction we propose that the number of involved users needs to be increased as representative information about the target marked needs to be collected. Third, the *dynamic interaction pattern* specifies wether manufacturers involve users only punctually or permanently (over several days, weeks etc.) into the innovation process. What dynamic interaction pattern is more appropriate for radical innovation projects? There are theoretical arguments for both alternatives. An argument for a punctually interaction pattern is that users posses sticky information with regard to their needs and solutions for those needs (von Hippel 1998; von Hippel 1994). A transfer of these sticky information to manufacturers causes high costs. It is therefore economically more reasonable that users develop incremental solutions to their problems which are then transfered to the manufaturer. This implies that manufacturer and users work separately on problems and meet from time to time to exchange their solutions (punctiform interaction pattern). A counterargument can be made however. This argument claims that manufacturers need to identify the tacit knowledge of users to develop radical innovations (Leonard-Barton and Doyle 1996; Mascitelli 2000). In this reasoning 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 (Leonard and Sensiper 1998; Madhavan and Grover 1998; Nonaka 1994). Comprising, no unambigous proposition can be made for the appropriate dynamic interaction pattern between users and manufacturers in radical innovation projects.

With respect to the impact of user involvement for manufacturers in radical innovations projects we distinguish effects on the idea generation capacity of manufacturers, product quality, quality of the manufacturer’s decisions (e.g. selection of concepts and prototypes), development time and development costs.

Empircal studies reveal that the involvement of users in the innovation process has positive impacts on all criteria (Biemans 1991; Herstatt and von Hippel 1992; Salomo et al. 2003). The question is wether this positive impact is also the case in radical innovation projects: are users productive or maybe even counterproductive in these projects? Our theoretical arguments imply a rather pessimistic view wether users are able to develop radically new ideas which in turn would increase the idea generation capacity of manufacturers for radical innovations. The same reasoning can be applied for substantial improvements of the quality of radical innovations. Those improvements require the development of own solutions which - according to the theory of social perception- users are not able to. However, we expect that user input with regard to user requirements enhances the use friendliness of radical innovations. Wether user involvement can have a positive impact on the quality of the manufacturer's decisions depends wether users can provide valid information in the development process of radical innovations. Empircal studies show that ordinary users are not capable to do so, because they have no reference framework to evaluate radical innovations. Besides that ordinary users might have a negative bias towards radical (Lynn et al. 1996; Schoormans et al. 1995; Veryzer 1998) innovations. The reason for this negative bias is that radical innovations cause high switching costs (behavior change, learning etc.) on side of the users while the benefit of radical innovations is difficult to anticipate. In contrast to ordinary users so called expert users however are able to validly evaluate early versions of a radical innovation (Schoormans et al. 1995). The key characteristic of these users is that they posses knowledge with regard to technologies similar to that of the radical innovation. This knowledge serves as a reference framework which enables expert users to provide valid evaluations of early concepts. The same reasoning can be applied to the impact of user involvement on development time and cost in radical innovation projects. Users that provide biased and unvalid information can even increase development time and cost as these “false” information induce additional development iterations. On the other hand valid information by users can decrease development iterations and therefore have a positive impact on development time and cost. To sum up, we propose that users are not able to subtantially improve the quality of radical innovations, but are capable to improve their use friendliness. No unambigous proposition can be fomulated wit regrad to the effect of user involvement on the quality of decisions as well as on development time and cost.

To explore contributions, appropriate interaction patterns and impact of user involvement in the innovation process of radical innovations we have conducted an empircal study. The applied methodology and findings of this study are introduced in the next section.

3. Research approach and methodology

To study the addressed research questions, we conducted an explorative case study analysis in the field of medical technology. The approach of explorative 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. The industry of medical technology was selected for two reasons First, former empirical studies reveal that users play an important role for new product development in this industry (Biemans 1991; Lüthje 2003; Shaw 1985). If we would observe no innovation ativity of users we could conclude that this is rather an effect of the high degree of innovativess 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. We choose concrete innovation projects as the unit of analysis and used a multi-case-comparison methodology. Five radical innovation projects were selected, including medical robots, computer assisted navigation systems, a radically new X-ray system as well as a radically new biocompatible implant. For the selection of truly radical innovations a seven-point-likert scale of the degree of innovativeness was used. This scale inluded a market dimension, a technological dimension and an organisational dimension. The R&D vice presidents of the firms were asked to evaluate innovations in their firm with regrad to this scale. Only those innovations were selected which matched the characteristics of radical innovations, exhibiting a high degree of newness on all three dimensions. To controll for memory bias of informants we only selected projects which were introduced to the market recently. Although we focused on direct impacts of user involvement for the manufacturer, the market and technological success of the radcial innovations was also evaluated by the R&D vice pesidents on a seven-point-likert scale.

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, CEO's and users. In sum a total of 45 interviews were conducted. Each interview had the duration of 2-3 hours. Any interview was recorded on tape and transcripted word by word. The final transcribed interview documentation contained approximately 1000 pages. To analyse the collected data, a content analysis framework was used. A system of categories for user characteristics, user contributions, user roles, and impact on the manufacturer was developed. The category systems were developed both deductively (based on existing theories and concepts) as well as inductively (based on the collected data). The inductive component reflects the explorative nature of the study. Each category was specified with several indicators which in turn were specified by operational definitions. To controll for informant bias only those statements were selected for analysis which had a high agreement betweeen the interviewed experts. Table 1 provides an overview with regard to the selected radical innovation projects.

Case	**Product description**	**Manufacturer**	**Innovation success** MS: Market success TS: Technological success	**Number of inter-views**
SPOCS	Computer assisted navigation system for neurosurgery	AESCULAP	MS: middle TS: high	9
orthoPilot	Computer assisted navigation system for orthopaedics	AESCULAP	MS: high TS: high	10
URS	Medical robot for neurosurgery	FRAUNHOFER INSTITUTE	MS: middle TS: high	8

GCF	X-rax system based on grid-controlled fluoroscopy	PHILIPS	MS: high TS: high	9
IMPLANT	Biocompatible implant	Anonymous	MS: high TS: high	9

Table 1: Selected radical innovations for case study analysis

In the next section we introduce the findings of our study. We differentiate our findings according to the the role of users, user-manufacturer interaction patterns and the impact of user contributions on manufacturers.

4. Findings

4.1 Role of users

4.1.1 Role of users in the idea generation phase

We analysed the trigger of the innovative activities, roles of users and corresponding characteristcis in that phase. The findings with regard to idea generation phase of the innovation process are presented in table2.

Case	**Trigger**	**Role of users**	**User characteristics**	**Transfer of…**
SPOCS	User problem	Inventor	• Extrinsic motivation (P) • Openess to new technologies • Access to interdiciplinary know how • Resources for research	Technology outside of medical domain (computer science)
orthoPilot	User problem	Inventor	• Extrinsic motivation (P) • Openess to new technologies • Access to interdiciplinary know how • Resources for research	Technology ouside of medical domain (kinematics and computer science)
URS	User problem	Inventor	• Extrinsic motivation (P) • Openess to new technologies • Intrinsic motivation	Technology ouside of medical domain (kinematics and computer science)
IMPLANT	User problem	Inventor	• Extrinsic motivation (P) • Openess to new technologies • Access to interdisciplinary know how • Resources for research	Technology ouside of medical domain (textile engineering)
GCF	User problem	Claim formulator	• Extrinsic motivation (P)	………………………

Table 2: Role of users in the idea generation phase

In four cases (SPOCS, orthopilot, URS, IMPLANT) users were the original inventors. This observation is in strong contrast to our proposition which states that users are not able to develop own solutions. The question then is what motivated and enabled users to develop radically new ideas. With respect to motivational factors all inventive users faced severe problems that could not be solved by conventional technologies. For example the neurosurgeos in the cases SPOCS and URS faced precision needs in the submillimeter area which could not be met by standard neurosurgical instruments. Due to the extremely high precision needs of neurosurgeons these users can be categorized as so called extreme users. The experience of coming to the edge with conventional technologies motivated the inventive users to search for completely different solution principles. This type of motivation can be categorized as an extrinsic motivation as it is induced by a specific problem (labeled as extrinsic motivation (P)). The idea generation process of the inventive users followed a common pattern in all four cases. Users abstracted from their current use context by searching for relevant technologies far outside of their medical domain. Therefore an openess toward new technologies was a key prerequisite that all inventive users shared. Once relevant technologies were recognized users transfered their solution principles to the medical domain. Thus the inventive users conducted analogical reasoning which is considered as a key source for radically new ideas (Dahl and Moreau 2002; Genter 1989; Ward 1998). For example the neurosurgeon in the case URS looked for solutions to prevent the trembling of the neursurgeon’s hand and to realize precision in the submillimeter area. In his search for solutions the inventive neurosurgeon looked into nuclear power plants. Analogous to employees in nuclear power plants which need a transmitter beteween them and the fuel elements a neurosurgeon needs a transmitter between his hand and the patient. By this analogical reasoning the inventive neurosurgeon developed the idea that the kinematic principle can be applied to neurosurgery. As robotic systems are based on kinematics the idea of a medical robot for neurosurgery was developed. With regard to enabling factors for the development of radically new ideas two types of inventive 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 truly creative thinking as state-of-the-art technologies could be perceived by surgeons. According to the concept of absorptive capacity, access to interdisciplinary know-how increased the creative capacity of the users. Another contectual factor of this user group were resources for research (time, money, personel). These resources enabled this group of inventive users to perceive technologies outside of the medical domain and to think about possible technology transfers. The second user type did not have these supportive factors. However this type exhibited a high amount of intrinsic motivation which in turn allowed to compensate for missing contextual factors. Beside a high problem pressure this user type regarded the search for radically new ideas as kind of a hobby and spend a large amount of spare time on it. Based on the identified characteristics of inventing users an explorative model can be derived which explains why and how users develop radically new ideas. This explorative model is illustrated in figure 1.

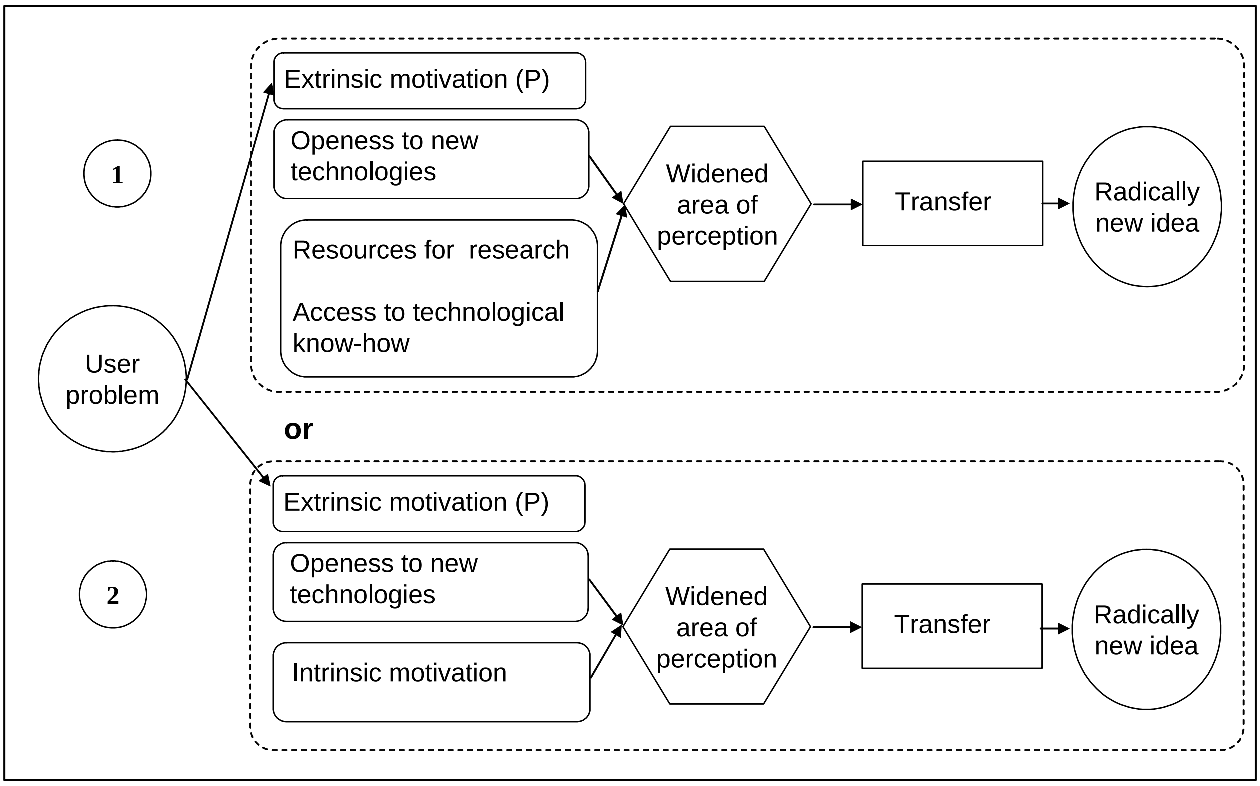

Figure 1: Users as inventors of radical innovations– an explorative model

It is interesting to note that the inventive users in our case studies 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 illustrate that point we 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. What differentiates the inventive users in our cases than from lead users in the classical sense? The first group of inventive users differs from lead users as they were embedded into a supportive context that inspired and enabled the generation of ideas for radical innovations. Our findings therefore highlight the importance of contextual factors. The second group of inventive users exhibited a strong intrinsic motivation which is also not accounted for in the lead user concept.

The case GCF is contrasting to the other four cases. In that case users did not develop the idea. One explanation can be found in the nature of the idea. The technology of GCF implies minimal pauses of X-Rax exposure which in turn leads to a loss in pictures. The loss of pictures was perceived by radiologists as a danger for misleading diagnostics. Picture loss was regarded as a tabu. The idea of GCF therefore had a "prohibitive disadvantage" in the percep-

tion of radiologists. This “prohibitive disadvantage” was a barrier for creative thoughts of radiologists with respect to a GCF technology. In the case of GCF an internal engineer of PHILIPS generated the idea instead.
Next we introduce the findings with regard to the development phase.

4.1.2 Role of users in the development phase

The findings with respect to roles of users and critical characteristics in the development phase are presented in table 3.

Case	**Role of user**	**User characteristics**	**Development contribution**
SPOCS	Networking Developer	• Extrinsic motivation (P) • High competence in user domain • Competence in technological domain • Tolerance of ambiguity • Openess to new technologies • Access to interdiciplinary know how • Resources for research	• Identification and involvement of experts and manufacturers • Active development contribution in user domain • Active development contribution in technological domain
orthoPilot	Networking Co-developer	• Extrinsic motivation (P) • High competence in user domain • Tolerance of ambiguity • Openess to new technologies • Access to interdiciplinary know how • Resources for research	• Identification and involvement of experts and manufacturers • Active development contribution in user domain
URS	Networking Claim formulator	• Extrinsic motivation (P) • Openess to new technologies • Intrinsic motivation • Imagination capabilities	• Identification and involvement of sponor, technology experts and manu-facturers • Passive development contribution in user domain
IMPLANT	Networking Co-developer	• Extrinsic motivation (P) • High competence in user domain • Tolerance of ambiguity • Openess to new technologies • Access to interdiciplinary know how • Resources for research	• Identification and involvement of technology experts and manufacturers • Development contribution in user domain
GCF	-----------------------	• Extrinsic motivation (P) • No imagination capabilities	--

Table 3: Role of users in the development phase

The case study analysis reveals that the inventive users took over roles in the development phase that constitute classical functions of manufacturers. The inventive users identified those technological experts (e. g. research institutes) and potential manufacturers that were required to transform their radically new ideas into first prototypes and marketable products. Once they identified relevant partners the inventive users established and organized this innovation network. Therefore users took over the *networking* in the development process, a role that is classically associated with manufacturers. In the four cases in which users originally invented the radical innovations, we therefore observed a pattern which contradicts conventional thinking about the management of innovation. Conventionally thinking, we assume that manufacturers involve users in certain phases of the innovation process. However, in four of our five cases we oberserved the opposite pattern: users involved manufacturers in the innovation process in order to transform their radically new ideas into first prototypes (URS, IMPLANT) or to transform their first prototypes into a marketable product (SPOCS, orthoPilot).

To exemplarily illustrate the networking activities of inventive users we refer to the case URS. In that case the neurosurgeon who developed the idea for a medical robot first contacted a graphic artist who visualized his ideas by drawings. Next the inventive user contacted a graphical design firm to transform the drawings into virtual simulations. These simulations were introduced by the inventive user at several medical conferences. By these publication activities the manufacturer SIEMENS got aware of the idea. At that time SIEMENS was in preparation of its 150 anniversary celebration and was looking for feasable visions in medical technology that could be presented at this event. The inventive surgeon contacted SIEMENS which agreed to finance the development of a first prototype. However SIEMENS had no technological knowledge or core competence for the development for a medical robot at that time. In search for a suitable technology partner, the inventive user identified the FRAUNHOFER INSTITUT as a worldwirde leading competence center in robotics. He contacted the engineers of that institute and convinced them to develop a first protoytpe. The entire budget for this project was provided by SIEMENS. Figure 2 illustrates the networking activities of the inventive neurosurgeon.

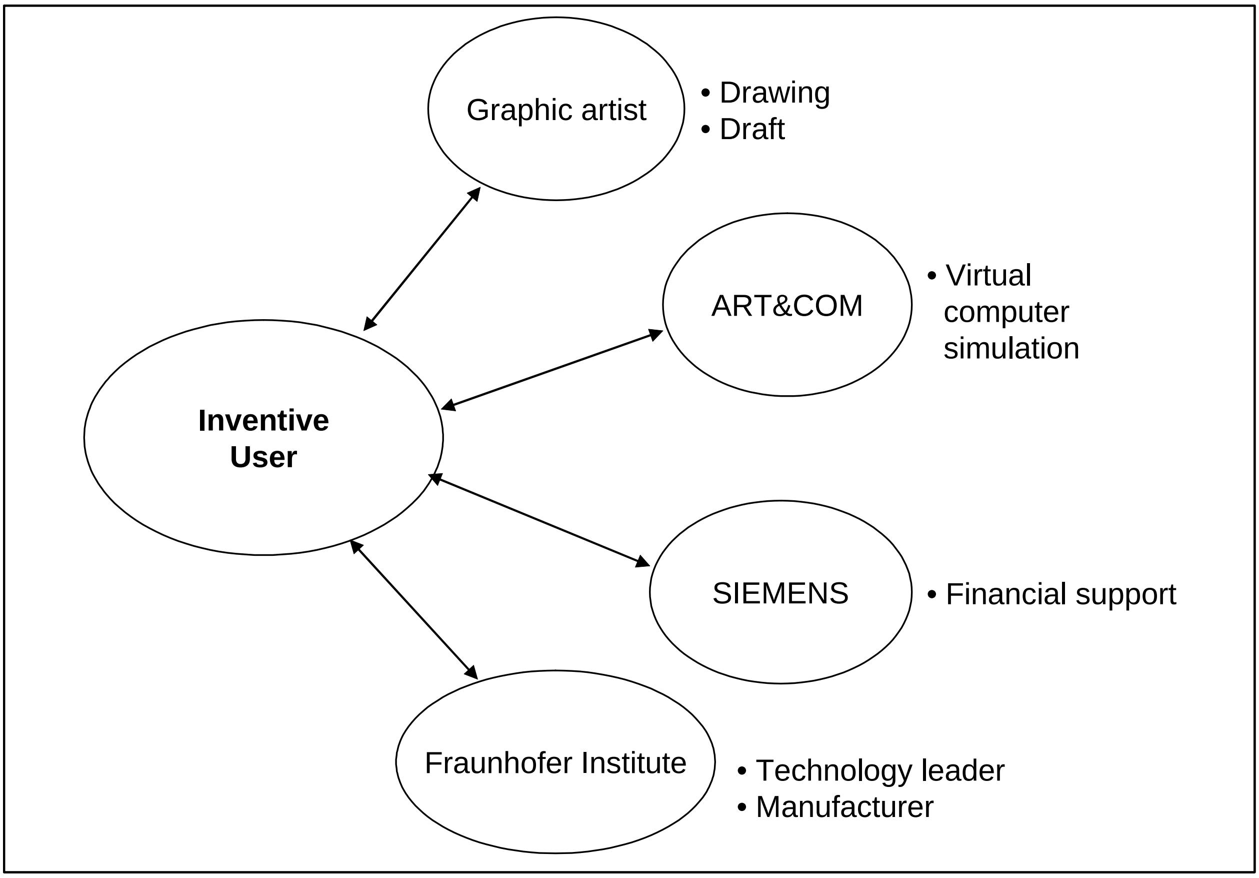

Figure 2: Networking activities of the inventive user in the case URS

In the cases SPOCS, orthoPilot and IMPLANT the inventive users engaged in similar networking activities. This observation raises the question why users took over such a challenging and time demanding role. The explanation might be a combination of three factors. First, the users developed the ideas by themselves without any involvement of technological experts and manufacturers. Second the users did not have all the competencies and material resources required to transform their ideas into prototypes and marketable products. With regard to competencies users lacked either technological or marketing knowledge. In addition, the inventive users did not have the financial, temporal and human resources that were necessary to develop prototypes and marketable products all by themselves. For this reason, the inventive users were dependent on external support by technological experts and manufacturers. Third, potential manufacturers were not willing in this early phase to commit themselves to the entire project management of the prospective radical innovations. Manufacturers were rather reluctant to engage into the realisation of the ideas. The reason was that the radically new ideas did not meet the core competencies of the manufacturers. In addition the manufacturers were detered by the high technological and market uncertainties affiliated with these innovations. It should be noted that the reluctance of manufacturers, although understandable, was not the proper reaction. The associated new products turned out to be successful. As manufacturers did not commit themselves to the project management it was on the inventive users to take over that role at least temporalily. A lack of knowledge and resources as well as the missing commitment of manufacturers in the early phases therefore explains why users engaged in innovation networking. The driving force for these exeptional activities was the motivation to transfrom their own ideas into real-world-products.

Besides networking the inventive users took over another classical function of manufacturers. The inventive users played the role of *developers* or *(co)-developers*. This finding contradicts our proposition which supposes that users are not able to deliver active development contributions for radical innovations. What characteristics enabled users to do so? A case comparison of user characteristics and associated development contributions implies a swell modell 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 users domain. Being the standard routine of ordinary users in incremental innovation projects, our case study analysis reveals that in radical innovation projects even this type of contribution requires distinct characteristcs on side of the user. The cases show that users need an extrinsic motivation caused by a current problem, an openess to new technologies as well as imagination capabilities. This finding can explain why so called opinion leaders are not necessarily suitable claim formulators in radical innovation projects. Opinion leaders might lack one of these three prerequisites. Particularly an openess toward new technologies can not be necessarily be presumed with opinion leaders as their status is often based on conventional technologies. In the cases GCF, URS and IMPLANT opinion leaders were indeed opponents of the innovations and not capable to validly evaluate concepts and prototypes. Our observation confirms results from former empirical studies which show that opinion leaders are not necessarily capable to recognize the benefit of radical innovations in the prototype stage (Lynn et al. 1996; Salomo et al. 2003). The case GCF differs significantly from the other cases. In this case the perceived “prohibitive disadvantage” of the GCF technology impeded users to deliver any kind of development contribution at all.
The next layer constitutes active development contributions in the user domain. The case studies reveal that users need an additional set of characteristics to perform on that layer. First, users need to have a high competence in their medical domain. The reason is that this layer contains the development of own solutions. To develop own solutions for radical innovations one needs to have a profound understanding of the elements, the causes, and effects of a certain domain. In addition users need to have tolerance of ambiguity. This characteristic means that users must be able to handle a high amount of uncertainty with respect to the final output of their development efforts. In the early phases of the radical innovation process a developing user does not know wether his efforts actually lead to a feasable solution. Users therefore face a high amount of uncertainty. First, users do not know wether their development investments (time, financial resources etc.) will ever pay off in a feasable solution. Second, users do not know wether their soutions might be marketed by a manufacturer. As radical innovations do have much longer development times as their incremental counterparts,

users that play the role of co-developers for radcial innovations need to have ambiguity tolerance to continue their efforts. The case study analysis reveals that active development contributions require two contextual characteristics in addition. First, users need to have access to technological know-how. The explanation for the importance of this contextual factor is twofold. On the one hand, users rely on complementary technological knowledge for the development of own solutions in their domain. For example, the team of innovative users in the case IMPLANT developed a camera system to measure the pressure on the abdominal wall. For this development the users were dependent on technological knowledge with regard to camera systems. On the other hand, access to technological know-how is critical for innovative users in order to get immediate response with respect to the technological feasability of their solutions. This feed-back can be leveraged by an innovative user in an iterative process to improve the own solution. In the case orthoPilot the innovative user developed the biomechanical solution of the computer-assisted navigation system for orthopaedics. By having acess to technological knowlege of computer science which was hold by the co-developing engineer, the innovative user was able to iteratively improve his solution in the medical domain. Generally speaking, access to technological know-how is important for active development contributions of users as radical innovations emerge by a symbiosis of technological and use-related knowledge bases. Second, users need resources for own research activities. One explanation why this contextual characteristic is critical on that layer might be the high complexity of such a task. The development of radically new solutions in the user domain is a highly complex and challenging task. In addition, this task does have a high degree of newness to the user. Therefore users need to intensively deal with the specific subject at hand. For these highly creative activities users need intellectual free space and resources such as time, facilities, and funds. To sum up, specifc characteristics enable users to realize active development contributions in their own domain. Considering these characteristics, it becomes evident that users as development partners for radical innovations do have a completely different profile as those users that are associated with conventional marketing research.

To reach the highest layer, active development contributions in the technological domain, users need technological competencies in addition. The case SPOCS illustrates that point. In this case a team of innovative neurosurgeons developed not just the idea, but also a first prototype of a computer-assisted navigation system for neurosurgery. This was possible as the users combined all the complementary technological knowledge that was necessary for this development. The required technological knowledge contained know-how on mechanics, computer programming, and electronics. One innovative user was a professional watch maker before he started his educational track for neurosurgery. He therefore had the technological know-how with respect to mechanics. Another user trained himself autodidactively in computer programming until he had profound computer programming skills. Yet another neurosurgeon on that user team had a profound background in electronics. Obviously users with a diverse set of technological capabilities (“cross-qualification”) are a relevant group as development partners for radical innovations. Our case study analysis reveals that users that are capable to perform on this highest layer are rather the exception than the normal case. Mostly users focused their development activities on the user domain. One explanation for this observation lies in the nature of radical innovations. These innovations incoporporate new and highly complex technologies. To develop technological know-how with regard to these technologies requires a separate educational track. The large majority of users does not have the time as well as the absorptive capacity to build up relevant technological competencies for radical innovations. Therefore our proposition with respect to the dominant domain of development contributions by users can be confirmed. The case SPOCS however demonstrates that exceptions to that normal case are possible. The swell model with its three distinct layers is illustrated in figure 3.

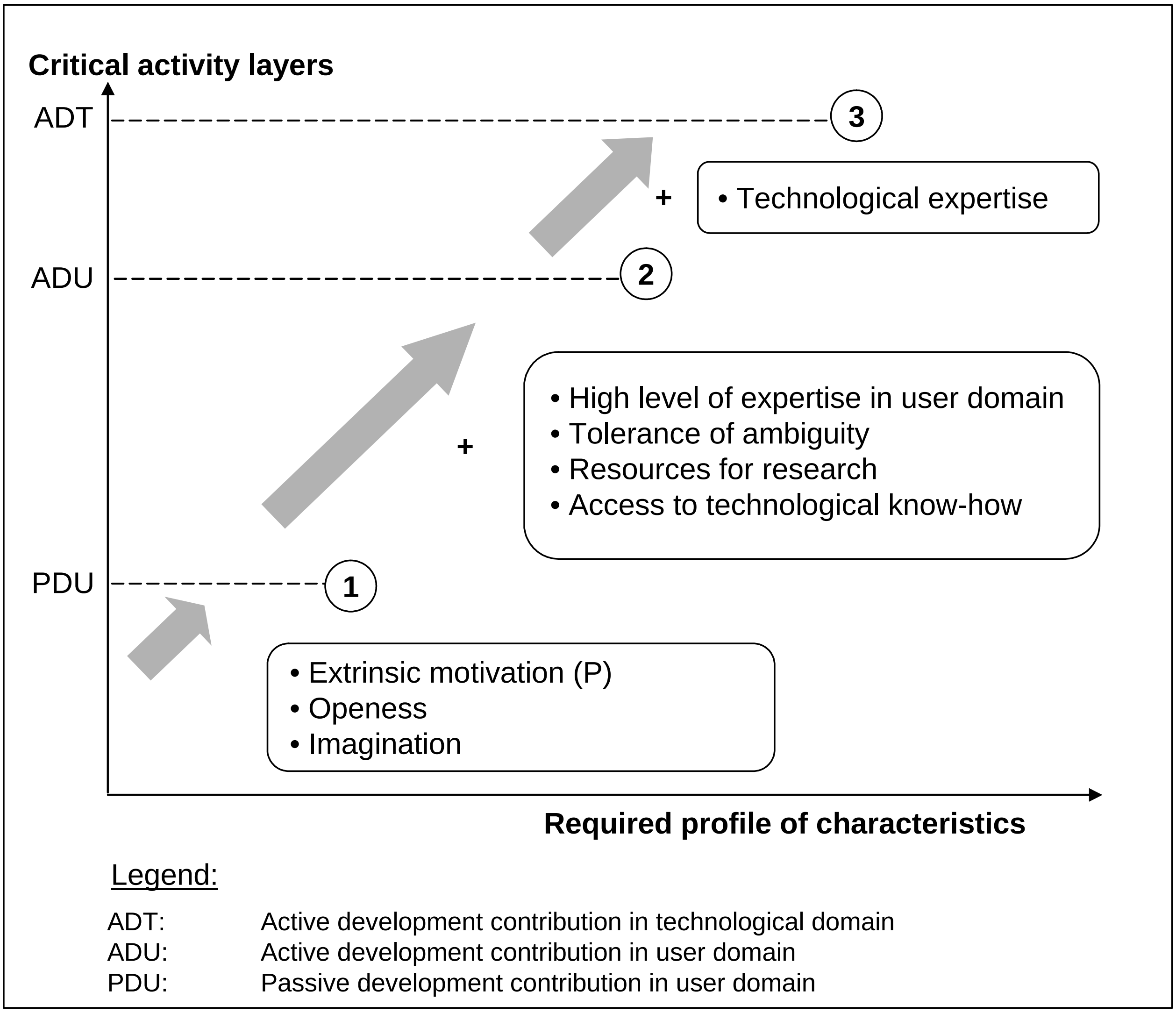

Figure 3: Swell model of development contributions by users for radical innovations

The model provides a framework that explains which characteristics enable distinct development contributions by users in radical innovation projects. Still open ,however, is the question what drives users to realize specific layers. One proposition is that the extent of motivation plays a critical role: higher layers require a higher amount of motivation on side of the user. One explanation for this proposition is that higher layers demand higher cognitive and temporal effort on side of the users.

In the cases SPOCS, orthoPilot, URS and IMPLANT the inventive users did not just play the role of inventors, networkers and developers, but also as successful testers. By testing first prototypes successfully they prooved the clinical relevance and benefit of their inventions. These successful tests of first prototypes marked a milestone for the successful market introduction of the radical innovations. Playing multiple roles the inventive users dominated the the entire development process. This result is in sharp contrast to our propsition which supposes that the innovation process of radical innovations follows the manufacturer active paradigm. In fact, the dominant role of the inventive users that took over classical functions of manufacturers throughout the idea generation and development phase points out that the innovation process of the four radical innovations followed the user active paradigm. In the cases SPOCS, orthoPilot and IMPLANT the prospective manufacturers entered the innovation scene not until a first prototype had been developed. Due to the high degree of technological newness and complexity of radcial innovations the observation of the user active pardigm is rather surprising.

4.2 Interaction between users and manufacturers

With regard to the interaction dimension the results of our case study analysis confirm our propositions. We find that face-to-face interactions are required between users and manufacturers in radical innovation projects. This result can be explained by the nature of information that users transfered to the manufacturer. This information was highly complex and therefore required additional explanations by the users. In our cases complex medical information with respect to surgical procedures and medical solutions was transfered to the manufacturer. To gain a basic understanding of the ideas and solutions of the inventive users the manufacturers' engineers needed to interact very closely on a face-to-face basis with the inventive users.

Also our proposition with respect to the number of users is confirmed. Our study shows that only a very small number of users was active idea generation and development. An explanation for this observation is that only an exclusive circle of users was capable for creative activities. As the radical innovations proceeded 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.

Users and manufacturers co-operated in a punctiform interaction pattern. This was possible as users developed solutions by their own. Users and manufacturers only met punctually for status meetings to report on the progress of their activities. The observed dynamic interaction pattern between users and manufactuers can be explained by the "sticky information" concept.

The inventive users had "sticky information" in the form of tacit knowlege about their medical context. From a cost perspective it was more efficient that manufacturers did not try to learn that kind of knowledge. Rather users leveraged their "sticky information" for the development of own solutions which were then handed over and explained to the manufacturers.

4.3 Impact of user contributions for manufacturers

Our case study analysis reveals that the users' contributions had a high positive impact on the manufacturers (see table 4).

Impact \ Case	SPOCS	ortho Pilot	URS	GCF	IMPLANT
Acquisition of idea for radical innovation	X	X	X		X
Reduction of development time	X	X	X		X
Reduction of development cost	X	X	X		X
Substantial improvement of product quality	X	X			X
Increase in use friendliness	X	X	X		X
Improvement of decision quality	X	X	X		X
Increase of internal barriers				X	

Table 4: Impact of user contributions on manufacturers

In those cases in which users played multiple roles as inventors, networkers, developers and testers (SPOCS, orthoPilot, URS, IMPLANT) the manufacturers who took over the users' ideas and solutions benefited significantly. In these cases manufacturers not just gained ideas for radical innovations. By the networking activities the inventive users also impacted positively on the development time and –cost. The active development contributions of the inventive users led to substantial improvements of product quality. Therefore, our proposition that users are not capable to substantially improve the quality of radical innovations has to be rejected. The testing role of the inventive users led to an increase in use friendliness of the radical innovations which turned out to be an important factor for market acceptance. Finally, the information provided by the inventive users led to an improve in the manufacturers' decisions. Based on the users' information the manufacturers selected the "right" prototypes and set the "right" priorities. The case GCF presents a different picture. In that case users were detered by the "probibitive disadvantage" of the technology and evaluated the radical innovation extremely negatively. This negative feed-back led to an increase of internal barriers at PHILIPS. Users supplied internal opponents with arguments against the innovation. Looking back the increase of internal barriers was a negative impact of user involvement as GCF turned out to be a highly successful innovation. To sum up, the contributions of the inventive users implied a substantial positive impact for the manufacturers that later introduced the radical innovations into the market. These users had a unique set of characteristics that is composed of motivational factors, diverse competencies and supportive contextual factors. This finding implies the recommendation for manufacturers to systematically leverage users with a specific set of characteristics for their radical innovation work.

5. Conclusions

Our findings have implications for innovation and marketing research as well as for corporate practice. The case study analysis reveals that the profile of users that are in the position to develop radical innovations differs significantly from those users types that are typically involved in conventional marketing research. Consequently radical innovations call for a completely different marketing research approach. Is the lead user concept a suitable approach? With regard to this question, it is important to note that the inventive users in our case sample do not meet the classical lead user definition. The reason is that the inventive users faced needs that the mass market also faced at the same time. However, the inventive users in our 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 the cases SPOCS and URS were neurosurgeons which can be categorized as extreme users as they faced the need for extremely high precison. The group of extreme users was identified as relevant for the search of lead users (Lilien et al. 2002; von Hippel et al. 2000). We therefore conclude that the inventive users have certain similiarities with lead users. However, our analysis reveals that additional characteristics are needed to contribute substantially to the development of radical innovations. First, the inventive users had a diverse set of competencies that qualified them for active development contributions. Second, the inventive users were embedded into a supportive context that enabled truly innovative activities. These contextual factors included both resources and access to technological know-how. Thus our study highlights the importance of supportive contextual characteristics for user innovation research.

The observation that in four of five cases users dominated the entire development process implies that the user active paradigm can also appear in radical innovation projects. This contradicts mainstream thinking whereby radical innovations are dominated by manufacturers. Particularly, the identified networking function of inventive users is an interesting aspect for further user innovation research. We still need to better understand what the causes for this phenomenon are. If users dominate development processes of radical innovations we might need to re-think our conventional wisdom that manufacturers involve users in innovation projects. Rather users involve manufacturers in the dvelopment process at a time where they lack the required resources to proceed by their own. This thinking implies that we need to develop characteristics of suitable manufacturers as co-operation partners of inventive users. Turning conventional lead user thinking around we would rather look for "lead manufacturers" as proper partners for inventive users. Our findings also have implications for the formulation of hypothesis in user innovation research. Traditionally, it is hypothesized that the involvement of users has a positive impact on innovation success. This hypothesis is confirmed on a broad empirical basis. However, these studies do not account for the degree of innovativeness. If the degree of innnovativeness is considered, we need to take into account which types of users are involved. Our findings highlight that the impact of user involvement in radical innovation is a function of motivational factors, competencies and contextual factors. Consequently, our results imply that the hypothesis formuation in user innovation research becomes more complex as the degree of innovativeness is considered.

With respect to corporate practice the identified profiles of inventive users can be leveraged by manufacturers as a search grid to more systematically identify highly creative users. Exemplarily such a search grid is illustrated in figure 4.

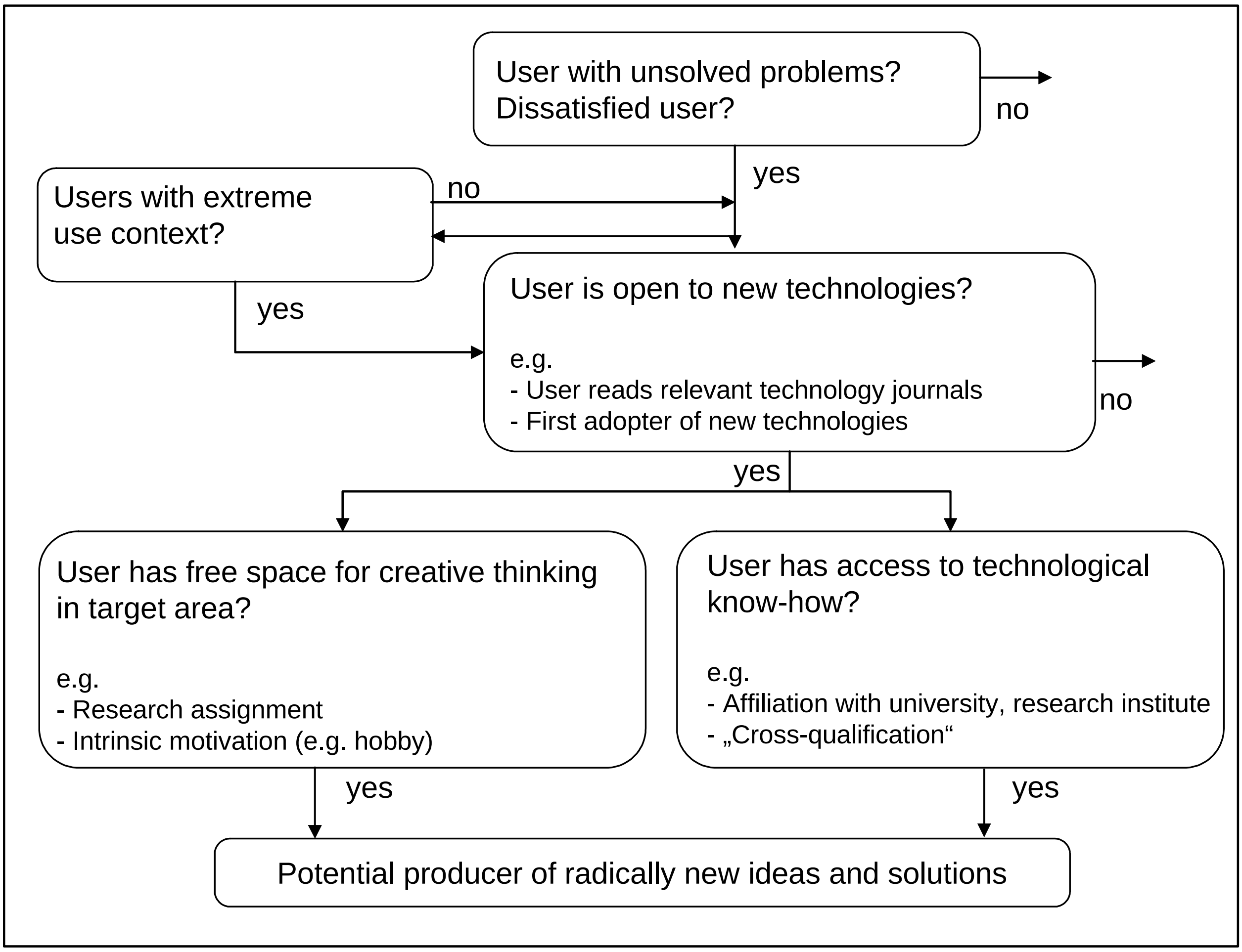

Figure 4: Search grid for users as idea and solution providers for radical innovation

The identification of such creative users can increase the creative capacity of a manufacturer as radically new ideas and solutions can be gained. One dimension of the organizational competence for radical innovation therefore is the capability to identify this group of high potential users. In similar form the swell model can be used as a search grid for the identification of such users that can play the role of (co)-developers for radical innovations. The swell modell implies a thinking in "user pyramids". We assume that the number of users decreases with higher layers as higher layers are more challenging and require additional characteristics. Consequently, we suppose that it is far more difficult for manufacturers 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 developmet contributions in the user domain). The substantial positive impact of the inventive users' contributions imply that manufacturers should involve such specific users into radical innovation projects. As only very few users are capable to deliver productive contributions for radical innovations manufacturers need to conduct the user selection process very diligently. Particularly, for small and medium sized manufacturers the identification of users that take over large parts of the development process is a useful strategy to develop radical innovations despite R&D budget-restrictions.

Recapitulating, our study sheds light on the role of users for radical innovations and discovered rather surprising results. One critical question however is wether the identified patterns also can be observed in other industries. The industry of medical technology has specific characteristics that limit the generalizability of our results. One important speciality of medical technology that is highly relevant for the focus of our study is that users in this industry are professional users. The observed users therefore differ from users that use certain products as part of their hobby (e.g. mountain bikers). Further research in other industries is needed to validate our results. It also should be taken into account that our research was explorative in nature. The goal was to explore critical user characteristics, appropriate interaction patterns and impact of user input in radical innovation projects. Future research should test our explorative models via quantitative studies. For example, the basic hypothesis that user contributions and user impact in radical innovation projects are a function of motivational factors, competencies, and contextual factors can be tested.

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