Where Do Inventors Get Their Ideas?

Sherwat Ibrahim, M. Hosein Fallah
Wesley J. Howe School of Technology Management, Stevens Institute of Technology, Hoboken, NJ 07030, USA

Abstract—Innovation is the engine of sustainable competitive advantage for technology firms. While companies provide for research and development and bring new products and services to market, every innovation can be traced back to a person's or a group of people's creativity and their ability to solve problems. The knowledge creation by individuals is what leads to new ideas or solutions that could become inventions and in turn innovations if they become commercialized and create economic value. This paper examines the individual knowledge creation process and explores sources of knowledge that influence the process. The paper presents the results of a nationwide survey of inventors in the telecommunication industry on the types and sources of knowledge that influenced them in coming up with their inventions. The study distinguishes between different types of knowledge- individual and collective tacit knowledge, codified and non-codified explicit knowledge and between sources of knowledge whether internal or external. The study shows varying levels of influence by different types and sources of knowledge. Among these factors, the collective tacit knowledge of the inventors' organization has the most influence.

I. INTRODUCTION

In today's knowledge economy, the key to a sustained competitive advantage is the ability to innovate and deliver new products and services to market ahead of competition. Innovation, however, is not something that corporate executives can simply order more. It is the output of a creative process often involving many people and complex dynamics. Understanding what drives this process and the factors influencing innovation is of great interest to R&D managers and corporate executives. One of the driving forces behind innovation is the direct interaction among researchers. This interaction facilitates the flow of knowledge between individuals and leads to the creation of new ideas. Knowledge with all its forms is viewed as a resource by organizations and by people working in organizations. It is the aim of this study to shed light on what forms of knowledge are viewed important by inventors in their creative process. We will use the classification of knowledge as presented in the literature, including codified and non-codified explicit knowledge, individual tacit knowledge and collective tacit knowledge. We also classify knowledge according to where it can be found, inside the company, or in the external environment of the organization.

II. FORMS OF KNOWLEDGE

In the course of interactions, people gain and exchange knowledge. The exchange of knowledge takes different forms. In distinguishing these differences, knowledge is classified into two general categories, tacit and explicit. "The distinction between tacit and explicit knowledge carries a potential for economic value and competitive advantage" [2, p.257]. Explicit knowledge refers to knowledge that is transmittable in formal, systematic language, while tacit knowledge has a personal quality, which makes it hard to formalize and communicate.

Polanyi [40, p.7] stated that "all knowledge is either tacit or rooted in tacit knowledge". He viewed tacitness and explicitness as two different dimensions of knowledge. Nonaka [37] explained that tacit and explicit knowledge are complementary and convert over time through a process of mutual interaction. Von Hippel [23] suggested that there is a tacit element in all knowledge when he talks about the "stickiness" of knowledge and the factors inhibiting the flow of knowledge from one location to another. Tsoukas, [48, p.15], stated that 'all articulated [explicit] knowledge is based on an unarticulated [tacit] background' and that to separate tacit from explicit knowledge is to miss the point. He disagrees with the view that they are two separate types of knowledge, and believes that tacit knowledge is the necessary component of all knowledge. Tsoukas, [48, p.16] referred to Polanyi [41] where he stated that as much as tacit knowledge can be 'linguistically expressed' when the person focuses his/her attention to it and makes it codified, explicit knowledge is also grounded in a tacit component where the extent to which knowledge can be codified [explicit] depends on the experience of the participants and on the situation. Spender [46] discusses the relationship between tacit and explicit types of knowledge and describes the boundary between them as 'porous and flexible' to allow for 'traffic' between the domains. While Cook and Brown [7] stress the distinction between tacit and explicit knowledge and state that neither type is a variant of the other, they consider each form of knowledge to be used as an aid in acquiring the other. Lawson and Lorenz [31] point out that the cycling between tacit and articulated knowledge is a key component in the product innovation process. Johnson et al [25], argue that scientific activities always involve a combination of know-how (tacit knowledge) and know-why (explicit knowledge). Lam [30] discusses the importance of the tacit component for acquiring knowledge in their 'knowing subjects', where individuals are not classified as knowing or not knowing, but are all knowing in varying amounts. Spring [47] states that the divide between tacit and explicit knowledge is not 'binary' and that it is dependent upon the previous experience of the members involved in the knowledge transmission. Kakabadse et al [26] stress that a sharp division between tacit and explicit knowledge does not exist and that at any given

moment one is conscious of only a small section of what one knows.

In summary, tacit and explicit knowledge are two complementary forms of knowledge, their combination and structure can change in relation to the situation and the level of attention of the 'knower' [2, p. 273].

III. KNOWLEDGE ACCESS AND TRANSFORMATION

Tacit knowledge is required to manage knowledge. Knowledge exists everywhere: in people's heads, in products and services, in companies, and in the surrounding environment. Innovation embodies new knowledge in the form of a solution to existing or new problems. We argue that the classification of tacit and explicit knowledge is relative to a particular situation and to the people involved depending on where they are in the knowledge exchange cycle. By taking a snapshot of the interaction between two people one can identify who is the originator of the knowledge and who is the recipient. The form of interaction specifies which knowledge is tacit and which is explicit at that point in time. Ancori et al. [2] underscore this relative dimension of tacit knowledge by arguing that what is tacit for one individual can be perfectly explicit for another. We show this in our model for knowledge accessibility (Fig. 1), where knowledge is classified according to where it is in the transformation cycle. In Fig. 1, on the left side we show knowledge that has not yet been accessed or made available. It includes individual tacit knowledge, cognitive tacit knowledge and collective tacit knowledge. The term tacit here relates to the ambiguous nature of this knowledge and to the difficulty for any external party to access it. On the right hand side, we show knowledge that has been expressed and that has become accessible. The degree of accessibility varies with the degree of codification that forms the explicit knowledge.

For individual tacit knowledge to be accessed and acquired by another person, it needs to manifest in an explicit form and move through explicit channels. If an individual is able and wants to express this knowledge, it then becomes explicit. When tacit knowledge first becomes explicit, it usually takes a non-codified form. Examples are when one blurts out thoughts about a particular idea, jumping from one point to another, or when a scientist jots down a formula on a paper napkin, or when a group conducts brain storming of an issue on a flip chart. Codification happens when someone repeats what he/she said in a more organized fashion or neatly writes down the thoughts in a memo or captures the outcome of the brain storming session in a document. The more explicitly the knowledge is iterated the clearer and easier to communicate it becomes, until it becomes standard information like in instruction guides, and manuals. Nonaka [37] calls this process of tacit knowledge becoming explicit, "externalization". Knowledge can go through many iterations until the non-codified knowledge becomes clear and easy to communicate. The expressed knowledge may represent only aspects of the tacit knowledge that remains with a person [40].

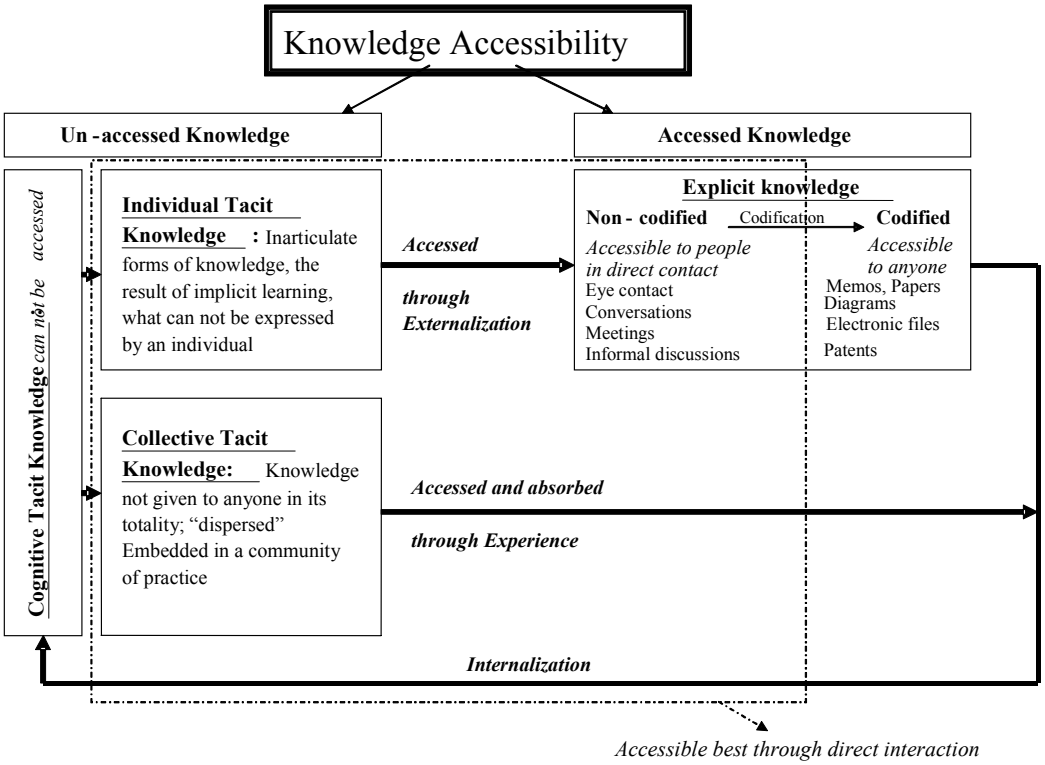

Figure 1 - Knowledge Accessibility and Tacit Knowledge

Some aspects of tacit knowledge may not be codifiable, such as a person's feelings or cognitive abilities. Skill is another form of tacit knowledge that cannot be fully codified. For instance, one can show or explain how to ride a bicycle and even document the steps on paper, but the actual know how that was gained through practicing and experience is impossible to codify and will remain tacit to any other person who wants to learn how to ride. We refer to this type of knowledge in our model as cognitive tacit knoweldge or cognitive ability. As it shows, this knowledge is always inaccessible to other people. While a person can explain how he/she reached a particular conclusion or arrived at an idea, one cannot pass this ability or teach it to another person.

Collective tacit knowledge is knowledge that is dispersed among a group and can be grasped in its totality. Collective tacit knowledge cannot be acquired from an individual. The problem is not in accessing the separate pieces of knowledge that might even be explicit and available to everyone, but rather is in accessing and understanding the whole picture or the context that gives sense to the scattered pieces of information. This type of knowledge needs to be experienced in its environment, by being in a particular place at a particular time. For instance organizations have unwritten rules. A new employee acquires the knowledge of how to operate in that environment over time by being in the organization and observing events as they happen. No one individual has or can articulate all such rules. Spender [45] refers to this collective tacit knowledge and how companies have a memory and are able to learn. Sharing the same background and culture helps one internalize such knowledge, and overcome the semantic barriers developed by communities [12]. Collective knowledge is also what Gibbons et al [18] call embedded knowledge, which cannot move easily across organizational boundaries. Lawson and Lorenz [31] recognize the importance of collective knowledge and collective learning in their study of regional competitive advantage, by examining the effect of tacit knowledge in the product innovation process.

The dotted area in Fig. 1 identifies the types of knowledge that is best acquired through direct interaction. All inventions and new ideas start as tacit knowledge embedded in someone's or a group of people's head(s). Often, the fastest, easiest, least expensive, accurate and, sometimes, the only way to access that knowledge is through direct interaction. Opportunities for direct interaction among researchers are more easily facilitated when they work and live close together. New information and communications technologies such as video conferencing and Internet are offering remote interactions among individuals and groups that facilitate to some degree the transfer of tacit knowledge. Compariative studies evaluating the use of computer mediated technologies (CMC) to face to face interaction (FTF) in the early stages of innovation highlight the importance of CMC as a complementary tool [6, 27, 39]. Effectiveness of such communication technologies needs to be studied and compared to direct and local interaction [15,24].

IV. KNOWLEDGE CREATION

Knowledge creation is the key source of corporate competitiveness and lies at the core of the innovation process. The better we understand the process of knowledge creation, the more likely innovative behaviors can be promoted in organizations. Fundamental to the resource-based concept is the role of organizations to develop and deploy scarce resources and capabilities that cannot be easily imitated. However, many are finding it challenging to create and manage knowledge in organizations, [4, 14].

The term knowledge creation has been used in the literature at two levels, the individual level where it implies the concepts of creativity and idea generation and at the organizational level where it's concerned with knowledge management and organizational practices that promote knowledge creation. The two levels are hard to separate, the reason being that knowledge itself can be viewed from an individual and a collective angle. We will classify the literature on knowledge creation into three groups, knowledge creation at the organizational level, knowledge creation at the individual level, and studies that linked both individual and organizational levels.

A. Knowledge creation at the organization level

According to Nonaka and Taekushi [38] organizational knowledge creation occurs as a result of a 'series of shifts' between the different 'modes of knowledge conversion'. Nonaka [37] identified four major modes of knowledge conversion in an organization: tacit to tacit, explicit to explicit, tacit to explicit and explicit to tacit. The different patterns of interaction between tacit and explicit knowledge represent ways in which existing knowledge can be converted into new knowledge. Nonaka and Taekushi [38] presented their popular 'Socialization, Externalization, Combination and Internalization' (SECI) model referring to 'socialization' as the first mode of knowledge conversion that enables the transfer of tacit knowledge through interaction between people in an organization. 'Externalization', the second conversion mode takes place when the knowledge holder attempts to articulate and codify his/her tacit knowledge. The third mode of knowledge conversion is 'combination', where explicit knowledge is converted into more complex sets of explicit knowledge and the fourth mode of conversion is "internalization" or learning where explicit knowledge is converted to tacit knowledge.

Nonaka builds on his model in Von Krogh et al [29], where the authors argue that the "creation of knowledge cannot be managed, but only enabled." This 'enabling' involves several steps; 'mobilizing' knowledge activities, creating the right 'context', managing 'conversations', instilling an overall 'knowledge vision' and 'globalizing' local knowledge. Organizations should use these 'enablers'

to better make use of its resources through its people. The internal culture of an organization should change from being aggressive and competitive to be more caring and trusting. Von Krogh [29], recognizes knowledge creation to be a 'fragile process' and advises managers to foster caring relationships between employees to overcome the uncertainties and conflicts of interest that take place in organizations. He suggests new incentive systems for knowledge sharing, training for mentoring programs and more focus on the importance of 'caring'.

B. Knowledge creation at the individual level

Studies carried out at the individual level include McFadyen and Cannella [35], who studied the relationships between research scientists in a biomedical firm and their impact on knowledge creation. They tracked the 'number' of relationships a person has and the 'strength' of those relationships. The study proved that the 'strength' of interpersonal relations had a higher marginal effect on knowledge creation than the 'number' of relations and that as relationships increased in number the returns to knowledge creation diminished. Chua [10] examined the variation in the level of social interaction and its relationship to the quality of the knowledge created in the development of curriculums of higher education. Findings show a strong relationship between the level of social interaction and the quality of the modules developed.

C. Creativity and Idea Generation

McAdam and McClelland, [33, p.87] review the literature and distinguish between creativity and innovation. They state that creativity is part of the innovation process, namely the front end, and that it is identified with idea generation unlike innovation that puts ideas into action in the form of end products and services. Heap [20] also related and compared creativity to innovation where he states "creativity is the synthesis of new ideas and concepts…where innovation is the implementation of creativity". The creativity process usually starts with the identification of a problem that needs to be solved, followed by a search for possible alternatives that could provide a solution. This search is highly dependent on the person's view of the problem, where a person unawarely explores his/her past experience and knowledge for a solution. In cases were a person cannot reach a solution on his own, he reaches out to other people and organizational sources of knowledge [17], that is why organizations need to understand what kinds of managerial practices foster knowledge sharing and creativity, and which practices destroy it [1]. Morris [36] linked 'idea generation' to the concepts of 'knowledge creation' and explained that idea generation comes as a result of grouping and integrating the sources of established knowledge. Idea-generation is considered the first stage in the product development process. Roberts and Fusfeld [42] identified idea generation as one of the most important and critical parts of the innovation activity. Koen and Kohli [28] recognize idea generation as a vital part in the front end of the innovation process. McAdam [34] examines the role of individuals and teams in idea generation and how they affect the creativity and innovation process in organizations. He reviews the literature on idea generation and identifies the need for more research in the front end of innovation.

D. Linking Individual Knowledge Creation to Organizations

Bhatt [5] argues that individual knowledge and organizational knowledge are different yet interdependent and that each level of knowledge requires different sets of management strategies to deal with. He proposes a framework that differentiates between both levels of knowledge according to the 'nature of tasks' and the 'nature of interactions' between the individuals in an organization. Individual knowledge is often expressed through personal creativity and self-articulation while organizational knowledge is revealed in the products and services generated by the organization. Fallah and Ibrahim [16] discussed how the dynamics of the conversion modes presented in Nonaka's [37] SECI model differ from one another when analyzed at the individual level. Chou and He [9] link four different knowledge 'assets', conceptual, routine, experiential and systemic to Nonaka's [37] four knowledge creation conversion modes (SECI). They develop a knowledge management framework built from individual and organizational sources of knowledge creation [8]. Bajaria [3], discusses the need to integrate the concepts of knowledge creation and knowledge management in order to have an updated knowledge base that remains accessible and useful.

V. SOURCES OF KNOWLEDGE CREATION

While research on sources of ideas for new products has been going on for more than a decade [11,13, 21, 22, 49], more empirical studies linking sources of ideas to creativity and the front end of innovation are needed [28]. McAdam [33] points out to the limited number of studies on idea sources and the lack of sector-specific analysis across industries. He criticizes that there are no studies that go further to examine why companies choose and exploit particular sources and that there is a lot of variation in the idea source categories, which can be confusing to researchers in the field.

The focus of past research has been on a source-based approach to idea generation with emphasis on internal knowledge sources like R&D and sales and external knowledge sources such as customers, markets and competitors. Von Hippel [21] used 'lead user' perceptions and preferences as sources for ideas for new products. In [22] he surveyed the sources of ideas coming from user, manufacturer or supplier and found that the results varied with respect to industry. Sowrey [43, 44] studied the sources and techniques for generating ideas for new consumer market products and concluded that marketing people followed by R&D were mostly responsible for delivering new ideas.

Yoon and Lilien [49] found that the 'customer requests' followed by 'market research' was considered the most important sources of ideas by manufacturers. Guimaraes and Langley [19] surveyed 108 US companies and found that internal teams and employees were the most effective source of new ideas. They also found the most commonly used 'methods' to generate ideas were internal meetings and brainstorming sessions. Several sources of new ideas have been tested. Examples are laboratory, management, distribution, supplier, consumer, marketplace, foreign, government, military and space programs [32]. Koen and Kohli [28] surveyed companies for the different sources that lead to the initial product idea of their innovations. The best sources of ideas varied with respect to the degree of innovation involved being radical, platform or incremental. R&D engineers and scientists, customers, senior sales managers, and operations engineers were selected as the most valuable sources. Interactions between customers and an organization's engineers and scientists were considered the most important source of radical and profitable ideas.

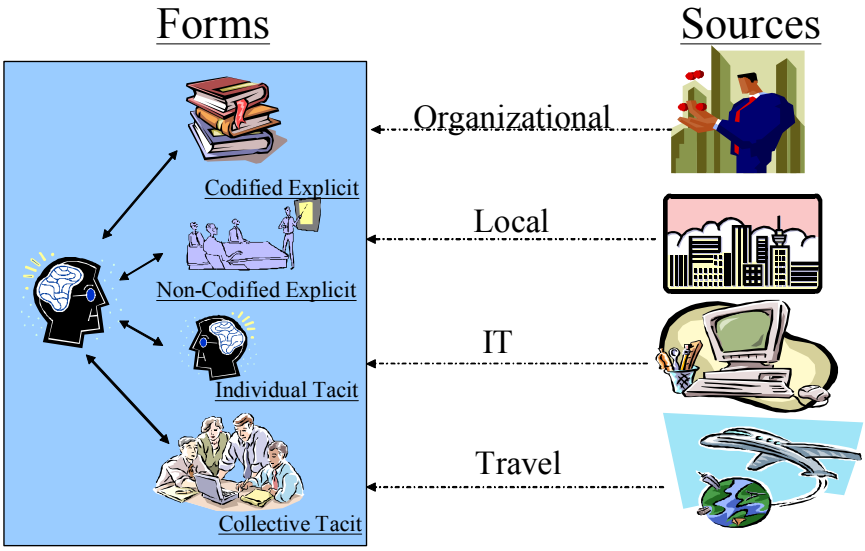

Figure 3 - Forms and Sources of Knowledge

In our study we investigate various sources of knowledge including 'internal' within a company and 'external' in the surrounding environment, and classify these sources into the different types of knowledge. Fig. 3 sketches a general view of these sources and interactions. Table 1 enumerates the possible types and sources of knowledge available for idea generation and knowledge creation by inventors. Our survey also included questions about the medium used in acquiring such knowledge.

TABLE 1- TYPES AND SOURCES OF KNOWLEDGE FOR INVENTION

Knowledge Types/Sources	**From within organization**	**From the local environment (other than the organization)**	**Using Information Technology**	**Other**
Codified Explicit Knowledge	• Patents and publications of employees. Internal memos • Documented methods and procedures, • Company presentations and products	• Local patents and publications. • Presentations, seminars, training sessions held by local chapters of societies and association, technology clubs; attended locally. • Products and prototypes exhibits locally	• Patents and publications found through the online search and access to remote data bases • Presentations • Searching for products and prototypes online	• Traveling to attend a conference or a presentation • Seeing a product or a prototype in a different geographical area
Non-codified Explicit Knowledge	• Having an informal discussion with a colleague • Looking at a draft or a preliminary version of an internal document. • Attending formal or informal internal meetings. • Company held training, knowledge sharing and brainstorming sessions.	• Having informal discussions with local individuals. • Looking at a preliminary version of a document in those local interactions. • Attending formal or informal local meetings. • Attending training, knowledge sharing and brainstorming sessions	• Telephone conversations. • Chatting online. • Video- conferencing	• Informal discussions with individuals in different geographical areas. • Attending a science, technology fair or symposia in a different

	• Social gatherings, conferences technology fairs arranged for by the organization.	with local groups. • Attending a local conference, technology fair or social events.		geographical area.
Individual Tacit Knowledge	• Interactions with a subject matter expert in your organization. • Interactions with a person working in a different business function in your organization	• Interactions with a subject matter expert you meet locally. • Interactions with a person working in a different business function you meet locally.	• Interactions with a subject matter expert through electronic media. • Interactions with a person working in a different business function through electronic media.	(Not measured)
Collective Tacit Knowledge	• Knowledge gained from monitoring the emerging technologies and reviewing state of the art innovations as a result of working for the organization. • Identifying a problem or need as a result of working for the organization. • Interactions with customers, suppliers, competitors and academia as a result of working for the organization. • Personal relationships developed with other researches as a result of working for the organization. • Being a member of a technology club or association in the organization. • The internal working environment of the organization.	• Knowledge gained from monitoring the emerging technologies and reviewing state of the art innovations locally. • Identifying a problem as a result of being in that location • Interactions with other customers, suppliers, and academia locally. • Personal relationships developed with other local researches. • Being a member of a local technology club or association • The local working environment. .	• Knowledge gained from monitoring the emerging technologies and reviewing state of the art on line.	Not applicable

VI. EMPIRICAL STUDY

In the previous sections we discussed the process of knowledge exchange and knowledge creation that leads to innovation. We conducted a survey of inventors in the telecommunications industry. Considering the link between inventions and innovations, we used a random sample of individuals who filed for patent applications in the past three years. The population we surveyed is primarily R&D engineers, who represent the innovators of this industry. To distinguish between the inventors and innovators, we asked the participants if their inventions were commercialized. Each participant was contacted individually and was then sent the survey electronically. We received 122 responses from a total of 250 surveys sent out.

The survey contained questions about the different types and sources of knowledge, localized knowledge spillovers, and general questions about the inventors' organizations and geographic location. We used a Likert scale of 1 to 5 to rate the influence of each form of knowledge, with 5 being the most influence. We have analyzed the responses for the importance of each influence.

Fig. 4 presents the mean ratings of the influencing factors for all respondents. Company environment and interactions with co-workers in terms of their tacit knowledge and non-codified explicit knowledge were considered by the inventors as the most important contributors to coming up with their inventions. Overall, the influences of collective and individual tacit knowledge were rated higher than the influence of explicit knowledge. This has significant implication for the way knowledge management is implemented in corporations.

We also wanted to examine if there were any differences between the responses we got from those who commercialized their patents and those who did not. This comparison is shown in Figure 5. The differences are statistically significant for all company influences except for codified explicit knowledge. The Significant differences could be due to the active role companies play in promoting and supporting commercialization of the promising new inventions, and the extensive interactions the inventors have with various internal organizations in moving their inventions through different stages of development and introduction to market. The inventors who commercialized their inventions also rated the overall influence of collective tacit knowledge and non-codified knowledge, on their coming up with their inventions, higher than those respondents whose inventions were not commercialized.

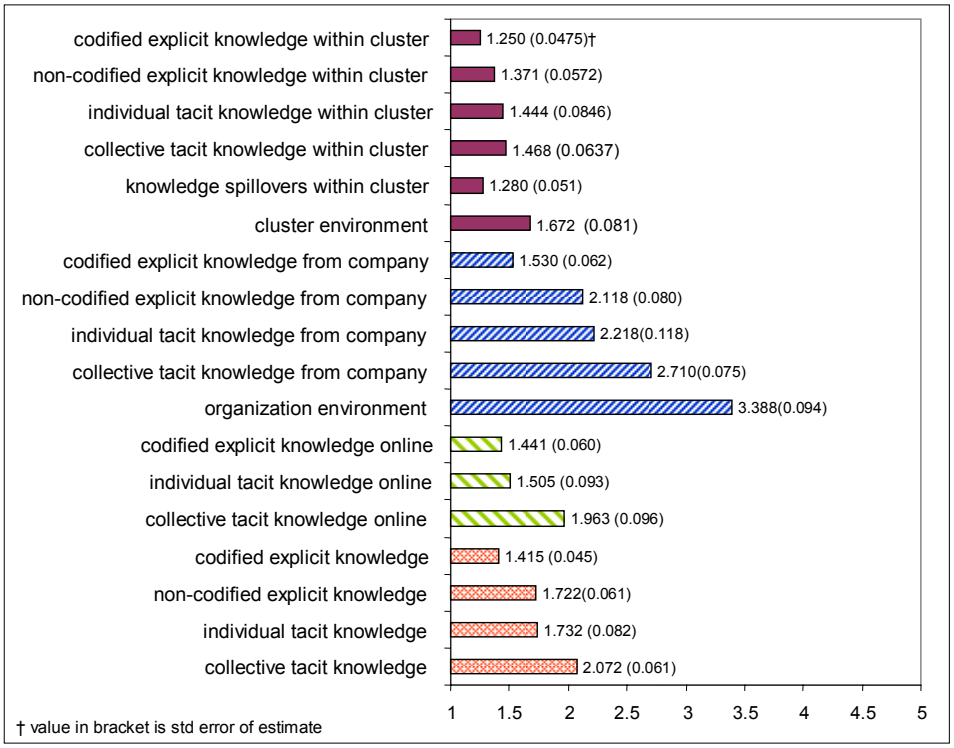

Figure 4. Drivers of Innovation – Mean ratings for all respondents (N=122)

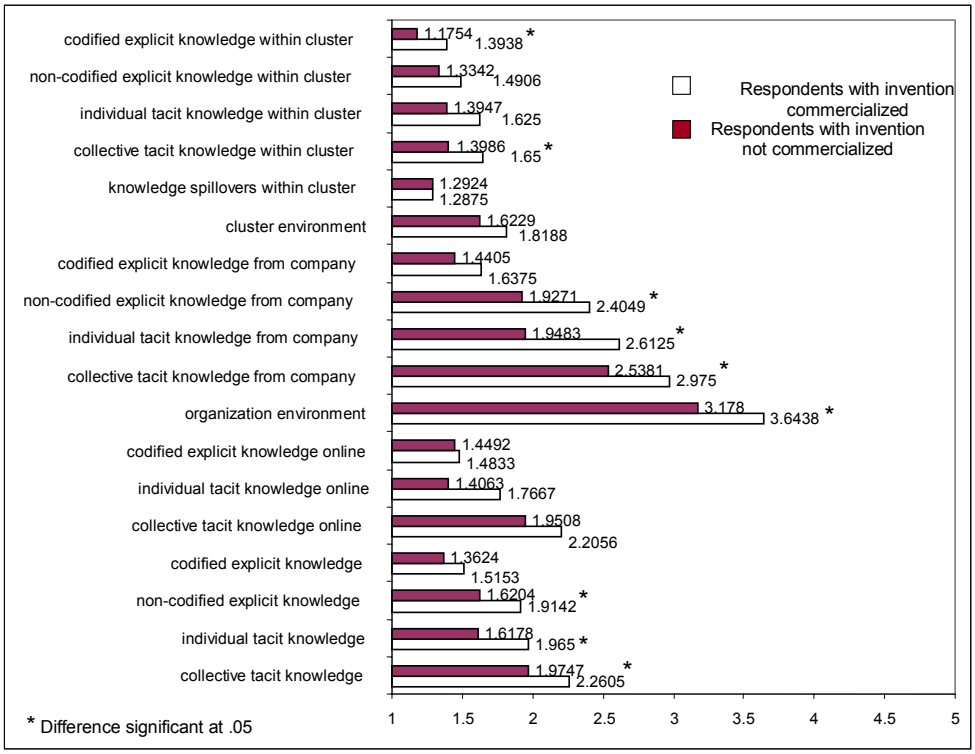

Figure 5. Comparison of responses for commercialized vs. non-commercialized inventions

VII SUMMARY AND CONCLUSIONS

In this paper the authors review the literature and provide a perspective on definitions and different forms of knowledge. The focus of the paper is on knowledge transformation and knowledge creation as drivers of invention and innovation. The authors present the results of an empirical study of inventors in the telecommunications industry. The study asked the inventors to rate various sources and forms of knowledge that had influence on their coming up with their inventions. Company environment, and interactions with co-workers in terms of their tacit knowledge, and non-codified explicit knowledge, were considered by the inventors as the most important contributors to their inventions. Overall, the influences of collective and individual tacit knowledge were rated higher than the influence of explicit knowledge. They also found that inventors who commercialized their inventions generally rated the influence of knowledge from their organizations higher than those who did not. These findings suggest that organizations can improve their innovation output by providing an environment that promotes and facilitates interactions among their researchers and with others within and outside the company.

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