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Spatio-temporal processes of knowledge creation

Johanna Hautala[a,*], Jussi S. Jauhiainen[a,b,1]

[a] Department of Geography and Geology, University of Turku, FI-20014, Finland
[b] Institute of Ecology and Earth Science, University of Tartu, Estonia

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ABSTRACT

This article presents a novel spatio-temporal framework for studying knowledge creation. To achieve this, we analyzed the recent literature on space, time and knowledge and conducted an empirical study. The intensive case was about four international distinguished university research groups in Finland in the fields of technology and science. Object, communicative and cognitive spaces with linear and relational times were used as tools for empirical analysis. Combinations of space and time bring out different aspects of knowledge. Knowledge processes of progressing knowledge (time-space), creating distinguished knowledge (space-time), and path-taking and bundling knowledge (spacetime) bind spaces and times closely together. Besides academy, the spatio-temporal framework can be applied to study the knowledge creation processes in art, business and local communities, for example.

1. Introduction

Knowledge creation is a process with spatial and temporal dimensions. Knowledge develops by building on and advancing from what one knows and what others have known. In creative work, ideas are not found, but made through preliminary knowledge and understanding (Flower and Hayes, 1980, p. 21). Knowledge creation is profoundly interactive, as other people and the environment affect the thoughts and actions of individuals. Knowledge is inseparable from the temporal processes of creation, interaction and interpretation as well as from contexts, or spaces, of creation. To understand more about how knowledge develops, it is useful to look more profoundly at how space and time come together in knowledge creation.

This article analyses spatio-temporal knowledge creation processes through theoretical concepts and empirical study. We study how space and time come together to get inside knowledge creation and to understand the knowledge creation processes. The main research questions are *What kind of combinations of space and time exist in knowledge creation?* and *What kind of knowledge processes do these combinations bring out?* We also answer three detailed research questions about the crucial elements for successful knowledge creation in temporally and geographically dispersed research groups. In particular, we ask the following: *What kind of "being there" in space progresses knowledge creation best? How does disrupted, slow and flowing time push knowledge creation forward?* and *At times when knowledge creation advances well, what perceptions of space and time do the members of the research groups share?*

In addition to physical "being there" in the shared geographical location of the group members, knowledge creation progresses best when "being there" extends to the cognitive space of shared understanding and mutual excitement in the group. Knowledge creation does not progress linearly. Temporal disruptions stem from mistakes, frustration caused by a difficult task and disadvantageous coincidences, whereas rigid project organization slows down the progress of knowledge creation and creates a feeling of time passing slowly. During exciting and hectic times when a research group works together in the same place, knowledge creation progresses well and time spent working is not counted – it feels like it is flowing in the background. All these time dimensions are crucial in creating internationally distinguished knowledge, because working through them requires and develops true passion and effort. Although the perceptions of space, time and progression of knowledge creation are individual, temporally these perceptions are shared in a group. Such shared perception emerges through event-bundles that the members of the research groups consider crucial when knowledge creation advances well. These bundles might be a workshop, a positive result of a funding application, and a difficult but successful collaboration task. The bundles collect researchers, artifacts, ideas and concepts together in a temporal way, which clarifies the future path of knowledge creation in a vast knowledge network.

* Corresponding author. Tel.: +358 2 333 51.
E-mail addresses: johanna.hautala@utu.fi (J. Hautala), jussi.jauhiainen@utu.fi (J.S. Jauhiainen).
[1] Tel.: +358 2 3335581; fax: +358 2 3335896.

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The concepts of knowledge, space and time are the starting point of the literature review. Therefore, rather than narrowing down the views to these concepts and the relations between them by selecting a certain strand of literature, we let the concepts guide us into the fields of economic geography (EG), organization and management (OM), science and technology studies (STS), and psychology-based research. Based on our review (see Section 2), there are two major challenges in this literature. First, space and time and especially their combinations are rarely addressed profoundly or combined adequately. This happens despite the fact that the studies recognize that space and time matter in knowledge creation, and that interest in addressing space and time has begun to grow (Beyers and Steyaert, 2012, p. 5; Birch and Cumbers, 2010; Brachos et al., 2007, p. 32; Crevoisier, 2004; Gertler, 2003; Hancock, 2006; McCormack and Schwanen, 2011; Nonaka et al., 2006; Powell, 2007, p. 321; Sonnentag, 2012; Vasquez and Cooren, 2013). Space is usually considered a material background and time as universal linear sequences. Second, in addition to the widely recognized importance of interaction in knowledge creation, one should pay specific attention to the cognitive interpretation process, also at individual and group levels. Many earlier studies have challenges analyzing the knowledge creation processes, i.e. the movement of knowledge (Malecki, 2010), sometimes misunderstanding knowledge creation with information transfer (Hautala, 2011a, pp. 50-56). In this view, knowledge is often measured according to its explicit dimensions through statistics on articles or patents, for instance, when the movement process of knowledge can be traced in physical space and linear time. Much of the elements related to the knowledge creation processes are left out, such as tacit and interpreted sides of knowledge and unpredictable coincidences of the creation process. Furthermore, current research often treats the organization as a sum of its individuals (Blaschke et al., 2012; Cook and Yanow, 1993). Therefore, studies in knowledge creation look at the inter-organizational dimension too often without recognizing the intra-organizational variety. In EG, this is one reason why the organization has become a “black box” in knowledge creation (Boschma and Frenken, 2006).

Addressing these challenges is essential when aiming to understand the complex process of knowledge creation for the following reasons. Knowledge is more than information because it is interpreted and exists in a continuum where explicit and tacit dimensions mix. To reveal processes of comprehensive knowledge, one has to adopt a theoretical and empirical framework accordingly. Such a framework addresses three aspects. First, knowledge creation is a process connected to multiple dimensions of time. Comprehensive knowledge is not only connected to linear time but also to relational experienced time (e.g. Csikszentmihalyi, 1997, see Section 2). Second, comprehensive knowledge is contextual and inseparable from multiple dimensions of space (e.g. Vallace, 2011) (see Section 2). Third, as we will show in the results section, within these dimensions, complex and comprehensive knowledge creation addresses many combinations of space and time.

We consider knowledge creation in spatio-temporal processes established in interactive networks in object, communication and cognitive spaces with linear and relational times as explained below (see also Sections 2 and 4). We take the knowledge creation processes as a starting point and show how the interpretation of knowledge into personal mental maps – networks of topics (Blaschke et al., 2012) – is important in those processes as well as group dynamics.

Our spatio-temporal framework of knowledge creation consists of space(s) and time(s) and their combinations. The following dimensions are identified through the literature analysis. *Object space* is the material environment of an individual: what one watches and hears. It provides geographical proximity or distance in the networks of people and laboratories. It focuses on essential objects, such as software, laboratory equipment and research articles used for knowledge creation. Other material settings, such as buildings, chairs and scenery are considered as well. *Communicative space* is formed of one- and two-directional interaction: not only what one watches and hears, but also what one sees, listens and responds to. The communication channels enable interaction between people, for example, through face-to-face meetings, emails, journals, and forums. The difference between communicative space and object space is that the aim of a communication event specifies whether it is one- or two-directional. One-directional communication takes place between an individual and an object. However, a person talking over the telephone is sharing knowledge with another person who has views and opinions, which is why this activity is two-directional even though it also includes using an object. In addition, reading a research article (object) can evolve into two-directional communication through referring to it or discussing it with the author. *Cognitive space* treats knowledge in the form of interconnected concepts, theories and ideas: what one can analyze, understand and discuss when interpreting interaction. It comprises mental models of individuals and shared mental models of groups. In cognitive space, one becomes cognitively closer or more distant. Knowledge is interpreted and justified, which is why knowledge does not exist without cognitive space, or without people. *Linear time* means time where events have sequential order, for instance, through clock and calendar. It also includes the *durée* of the life span of an individual and the *longue durée* of institutional time. *Relational time* is linear time experienced by individuals and groups.

In the empirical analysis of the case regarding international research groups, we indicate how to conduct in-depth empirical research on the knowledge creation processes through the spatio-temporal framework. Our framework with spaces (object, communicative, cognitive) and times (linear, relational) helps to identify three spatio-temporal dimensions in the practices of knowledge creation (see Section 4). The time-space is about linear stages of knowledge progress, the space-time is about flow and disruptions toward distinguished knowledge, and the spacetime is about path creating, bundling and widening for the advancement of knowledge. This framework can be applied to study the knowledge creation processes in many realms, for example in academia, art, business, and local communities. This is of vital interest for various disciplinary and interdisciplinary approaches regarding knowledge and innovation studies as well as for policy and practice in the respective fields. The management of spatio-temporal processes and contexts of knowledge creation is important for knowledge policies.

The empirical study here focuses on a narrow but important field of knowledge creation, namely academia. Around the world, universities are reformed to become more international and entrepreneurial (Etzkowitz and Viale, 2010), aiming at innovations and distinguished knowledge. Recent research confirms that groups outperform individuals in creating novel and innovative knowledge (Amin and Roberts, 2008; Nonaka and Takeuchi, 1995; Singh and Fleming, 2010). Therefore, knowledge is created in enterprises and universities increasingly in groups. Currently, research groups consist increasingly of scholars with different cultural and professional backgrounds who join and leave the groups. Multiple views and skills benefit the novelty aspects of knowledge (Intemann, 2009, p. 261) but such international groups face the opportunity and challenge of diversity (Maddux and Galinsky, 2009). Due to complexity of knowledge creation in international specialized groups, it is suggested to analyze knowledge creation more profoundly, through in-depth case studies dealing with a variety of groups (Bosch-Sijtsema et al., 2011, pp. 276–277; Chen et al., 2010, p. 240; Garcia-Perez and Ayres, 2009, p. 62; Nam et al., 2009, p. 781), as we do in this article. We study distinguished international research groups in the fields of technology and science. These research groups in selected universities in Finland are temporally clustered and dispersed.

To explain the role of knowledge in organizations, scholars have utilized various approaches from structural to institutional and further to evolutionary theories. They approach knowledge frequently from rationalist or constructionist perspectives (Amin and Cohendet, 2004; Cook and Brown, 1999; Ibert, 2007). These studies often lack cognitive dimensions to knowledge creation. Therefore, holistic and human-focused understanding of knowledge is needed for new insights (Jakubik, 2011). Recent research on knowledge development emphasizes the need for studies regarding the processes of knowledge creation (Hong et al., 2010, p. 62) and interaction, diversity and cognitive dimensions in knowledge creation (Harquail and King, 2010, p. 1619; Kearney et al., 2009, p. 581; Raes et al., 2011, p. 102). Common research practice has been to study the knowledge creation retrospectively based on managerial time-lagged *ex post* narratives. In this study, we intensively follow both individual researchers and research groups "here and now" for a period of about a year from the beginning of their research projects, including observation on site. We study how knowledge develops in the research groups through the moments and periods when researchers and groups do not yet know the outcomes of their activities. This also addresses the notions of earlier research that should focus on the early phases of knowledge creation (Evans, 2010, p. 760) and evolution of collaboration (Sundberg, 2010, p. 37). We also consider the achievements of these research groups over several years.

Following the introduction of this article, the second section introduces our constructionist-cognitive approach to knowledge. Later, we review the key literature of EG, OM, STS and psychology-based views that apply the concepts of space and time to knowledge. Building on this review, we present how space, time and knowledge have been identified as knowledge of space, knowledge in space and knowledge as space and these combined with linear and/or relational time. In the third section, materials and methods of the empirical study are presented, followed by the empirical analysis and results in the fourth section. The fifth and final section draws conclusions about the results, suggests implications for managers and researchers, discusses the significance of the results, and indicates challenges for further research.

2. Knowledge creation processes in space and time

In this article, knowledge is individually interpreted as "justified true belief" (Nonaka and Takeuchi, 1995, p. 21). Therefore, it is inseparable from the one who knows. Academic knowledge is justified in relation to the epistemic culture (Knorr Cetina, 1999). Knowledge is formed of tacit and explicit elements as well as of theory and practice (Ibert, 2007; Nonaka and Takeuchi, 1995). The easier, communicable explicit knowledge is expressed in codified form such as texts. Tacit knowledge is personal, contextual, and practical, and is difficult to communicate (Polanyi, 1983). Academic research groups have elements of tacit and codified knowledge. However, outside the conceptual consideration, knowledge cannot be strictly divided into tacit or explicit, but it exists in a continuum.

We adopt a constructionist-cognitive approach that acknowledges interaction and interpretation as the key processes of knowledge creation (Daft and Weick, 1984). According to the constructionist viewpoint, knowledge is a practice created in interaction (e.g. Amin and Cohendet, 2004). A group is the basic unit of interactive knowledge creation (Nonaka and Takeuchi, 1995). Interaction is composed of the knowledge-creating activity (or avoiding this activity) in relation to people and objects, such as applying machinery and software, discussing and moving in relation to others, for example traveling to meetings. One-directional interaction includes an individual and an object, whereas two-directional interaction includes people, sometimes utilizing objects (Berger and Luckmann, 1967; Nersessian, 2009). People have views, opinions and experiences, whereas objects do not. Human responses and discussions can challenge and evolve the thinking process more than software or laboratory equipment alone, which is why this interaction is two-directional (see Berger and Luckmann, 1967, p. 29).

The cognitive viewpoint focuses on the interpretation process. It allows drawing a simple but salient line between knowledge and information. Interpretation transforms information, or a chain of marks or a product, into meaningful and applicable knowledge (Davenport and Prusak, 1998, pp. 2–6). It allows a detailed look into the multiple understandings of knowledge in a group. Although a group can share interpretations (e.g. McComb, 2007), the interpretations by each group member are still unique.

We study the knowledge interpretation process through mental models. Ideas, concepts, statements and thoughts arising from interaction are organized into mental models as dynamic and incomplete representations of the world (Johnson-Laird, 1983; Kelly, 1955). To some extent, one can control, anticipate and make sense of one's surroundings and interaction through mental models (Weick, 2001). These mental models are organized into wider knowledge bases or mental maps, where networks of concepts and ideas affect thinking and acting (Huff, 1990). These knowledge bases change and widen because one learns and corrects false combinations through interaction. The mental models can be partly explained, or made explicit, but much of this knowing remains tacit (McComb et al., 2010, p. 265; Nonaka and Takeuchi, 1995).

Space or time is rarely applied as explicitly defined concepts in knowledge-related research (Amin and Cohendet, 2005, p. 465; Hancock, 2006, p. 621; Sonnentag, 2012). This is partly due to the complexity of these concepts per se. Sometimes, instead of "space", researchers use different but related concepts such as "context" (Asheim and Hansen, 2009; Gertler, 2003; Teece, 2000), "*ba*" (Nonaka and Konno, 1998) or "work environment" (Amabile et al., 1996). The understandings of time are frequently discussed with process-related terminology and the ways to collect empirical material over time or at one point in time. However, in recent years, research on knowledge creation has witnessed an increasing interest in treating space and time together. This development has taken place especially in EG, which has a long tradition of conceptualizing space and studying phenomena with spatial approaches, and in STS and OM, where the importance of context to knowledge is discussed (e.g. Nonaka and Konno, 1998; Powell, 2007).

For identifying the connections between space, time and knowledge in the knowledge research literature, we draw on Dodgshon (2008). First, space and time can be treated without explicit attention to each other. "Space" and "time" are not necessarily used in the same research and they are anyway written separately. Second, space and time can be seen as being interrelated but distinct in a few ways. Time can be spatialized into stages of development and space can be temporalized through rhythms (Crang, 2001, p. 200), or when geographical differences are studied in a historical context. This is "space-time", in which the hyphen indicates the connection but also their distinctiveness (Massey, 2005, calls this time-space). Third, time and space can also be seen as mutually constitutive without the possibility for their separation. Spatial consciousness evolves through the experience of time and vice versa. This is "spacetime", space and time written together without hyphen (or timespace as May and Thrift, 2001, call it). This terminology is used below in the analysis of the key literature.

2.1. Knowledge of space with linear time

The first perspective is knowledge of space with linear time. The dimensions of object space and linear time are identified from the knowledge of space perspective and applied later in this article for the framework of this study.

This perspective considers space and time as being simple categories, often used separately in knowledge research. Space is a geographical location, area, surface (Fritsch and Slavtchev, 2007; Herod et al., 2007; Liefner and Hennemann, 2011) or another material object on the earth, such as an office (Edenius and Yakhlef, 2007; Toker and Gray, 2008). Time is linear, having a past, a present and a future. Although knowledge and space are connected – since knowledge moves on the geographical surface – in the studies they can exist without one another. In addition, space and time can be treated separately from each other. This approach to knowledge of space with linear time is the most commonly used (Livingstone, 2010; Sismondo, 2010, p. 11; Taylor and Spicer, 2007, p. 327).

Space exists outside, between and inside organizations. In EG, space outside is the background for economic activities, whereas space between organizations turns the attention to networks and proximities (Coccia, 2008; Fritsch and Slavtchev, 2007; Weterings and Boschma, 2009). In STS, space is formed around science (Meusburger et al., 2010), and around the place in which knowledge has been created (Powell, 2007, pp. 311–313). In OM, space is mostly inside organizations (Taylor and Spicer, 2007, p. 327), where it has an effect on, for instance, communication patterns (Cummings et al., 1974; de Souza e Silva, 2006; Toker and Gray, 2008). This is also adopted in the architectures of science approach of STS (Powell, 2007, pp. 315–316).

Time is not usually explained explicitly. Its linear existence becomes clear in the analysis of empirical material, often collected only at one point in time (e.g. Huber, 2012; Westenholz, 2006). When knowledge creation is viewed as a continuous progress (Chia, 2002; Loasby, 2001, p. 393), time exists as an evolutionary process that takes place outside and between organizations. Knowledge is followed for longer periods, such as in spillover studies (e.g. Breschi and Lissoni, 2009) where knowledge spills outside and between organizations, and evolutionary EG (Boschma and Frenken, 2006, p. 281). In evolutionary EG, organizational routines are thought to be the main entry point to organizations (Boschma and Frenken, 2006, p. 277), but so far the methodology and methods for studying organizations are only in the developing phase.

A sequenced time of projects exists inside organizations, especially in STS and OM (Rodrigues Araújo, 2005; Yli-Kauhaluoma, 2009). Projects have a sequential schedule from beginning to end, and the periods include progress in stages that sometimes overlap (Adams and Bandt, 1983). In geographically temporally dispersed groups, synchronizing time across time zones is seen as crucial for knowledge creation (Brown and O'Hara, 2003, p. 1580).

The connections between space, time and knowledge are based on quite loose time-spaces. As the name – knowledge *of* space – of this perspective suggests, knowledge is well connected to linear time, but loose of space. Space and knowledge are bound together in start and end locations of moving knowledge. However, during its movement, the link between space and knowledge is less considered. Such an idea derives from the rationalist understanding of knowledge that dominates EG and OM (Ibert, 2007; Jakubik, 2011). Rationalist knowledge is mainly explicit and analyzable with statistics and mathematical modeling. Knowledge might be a "matter" of fact whose creation has to be witnessed (Shapin, 1988). In EG, it is common to consider that organizations possess knowledge. Therefore, knowledge is disconnected from individuals. The terminology (exchange, transfer, diffusion) suggests that knowledge moves as such without interpretation, in other words, cognitive processes are not considered (Hautala, 2011a).

Most knowledge research includes only an implicit assumption of connections between space, time and knowledge. In OM, "management" is the connection, since knowledge creation can be organized and managed in material space and linear time. Projects are scheduled, enterprises choose location and the interiors of offices can be designed to foster communication. In EG and STS, the connections derive from inter-organizational links that usually indicate movement or creation of knowledge over linear time, such as spillover (Audretsch et al., 2005), transfer (Coccia, 2008), accumulation, exchange and diffusion (Maggioni et al., 2007), decision-making (Cummings et al., 1974), production (Ortega Priego, 2003) or patenting (van Pottelsberghe de la Potterie and van Zeerbroeck, 2008). Though geographical proximity (in material space) alone is not enough to foster knowledge creation, it facilitates other important forms of proximities (Boschma, 2005, p. 61) and sharing of tacit knowledge face-to-face (Nonaka and Takeuchi, 1995). It eventually explains the formation of clusters in material space – simultaneously geographically closely located firms and institutions (Howells and Bessant, 2012, pp. 931–932). In fact, clusters are thought to catch and stop the movement of knowledge temporally.

Explicitly explained connections between material space, linear time and knowledge can be found in time-geography. This branch of research analyzes the temporal and spatial movement of people and artifacts. In its simplified applied version (see criticism for this version: Gren, 2001, pp. 214–215), peoples' everyday paths in linear time and object space (geographical and functional location) are traced (Hägerstrand, 1970). The study of the Nobel Prize laureates' life paths shows that many of them have shared the same locations during their life, suggesting that creative milieus contain places that attract skilled professionals in certain time periods (Törnqvist, 2004, p. 241).

2.2. Knowledge in space with linear/relational time

The second perspective is knowledge in space with linear/relational time. It reveals the dimensions of communicative space and linear/relational time that are integrated into the framework of the empirical part of this study.

This perspective considers that knowledge develops in interaction in space and time. This approach is rather rare in EG and OM, but is adopted in STS quite a lot. However, it is becoming more common, especially because of the growing interest in knowledge creation practices (Bathelt and Glückler, 2011, p. 68; Powell, 2007, pp. 316–320; Vogel, 2012, p. 1031). In EG, this perspective stems from the relational turn that has shifted focus onto micro-level studies inside organizations and toward complex and spontaneous features of knowledge creation (Bathelt and Glückler, 2011, pp. 6–7; Fløysand and Jakobsen, 2011, p. 328). In OM, the perspective is bound to "minor spatial turn" inspired by Lefebvre (1991) (Beyers and Steyaert, 2012, p. 4; Halford and Leonard, 2006; Taylor and Spicer, 2007). In STS, this perspective is related to the socio-spatial school and especially its laboratory ethnographies (Powell, 2007, pp. 316–317).

Space is seen as being both material and communicative in which people, ideas, information and rituals move and interact with space (Amin and Cohendet, 2005, p. 465; Frenkel, 2008; Houdart, 2008; Lorentzen, 2008; Schneider, 2010). Such communicative space can consist of networks like epistemic cultures (Knorr Cetina, 1999) and communities of practice (Wenger, 1998), and networks can include non-human actors, such as in actor-network theory (Latour, 2005). A widely applied framework into spatially interactive knowledge creation is *ba* (meaning "place") evolved around the work of Nonaka and Konno (1998) (e.g. Yamashita et al., 2009).

Time is either linear or relational. EG differs from OM and STS in its approach as regards the knowledge processes in time. EG focuses on managerial time-lagged representations of the knowledge processes. Surveys and interviews, usually answered by the managers, are collected after the results of knowledge and innovation processes are known. In OM and STS, researchers have conducted ethnographic studies on "here and now" processes of knowledge creation (Knorr Cetina, 1999; Orr, 1996; Wenger, 1998). These illustrate how the practices of individuals and groups are at the core of knowledge creation and go beyond the organizational boundaries (Orr, 1996; see also Scarbrough and Swan, 2004). Compared to the knowledge of space perspective, linear time is treated in more detail. For instance, O'Carroll (2008) and Ylijoki and Mäntylä (2003) apply the idea of *longue durée* of institutions (see Braudel, 1980), where the sequential practices of daily life are organized as greater non-flowing institutional times (Dodgshon, 2008, p. 9). Understanding of life's finiteness reveals the *durée* of the life span of a knowledge-creating individual (Giddens, 1981). Experienced relational time of knowledge creation challenges the seeming universality of linear time (Csikszentmihalyi, 1997; Dodgshon, 2008). It takes an unpredictable amount of (measurable) time to incubate thoughts (Van Looy et al., 2003, p. 20). An hour for an adult doing nothing might be a relaxing experience, whereas for a scholar in a hurry it is an unbearable situation.

Linear and relational times are not always clearly separable, as shown by "flow", an experience of creativity when being challenged by a difficult task and being able to rise above it (Csikszentmihalyi, 1997). The time in flow both flies and is stopped when a person is unaware of linear time of the working hours. The flowing time of knowledge creation is evoked by the change (Dodgshon, 2008, p. 9) that connects before, now and after (Bergson, 1983; Chia, 2002, p. 865).

Time, space and knowledge are connected mainly as space-times. The "in" of the knowledge *in* space perspective refers to the interactive processes of knowledge creation in social spatiality (Simonsen, 1996, p. 502). This view derives from the constructionist understanding of knowledge, where knowledge is the practice of knowing (Ibert, 2007) and (situated) learning (Macpherson and Clark, 2009). Constructionist knowledge accentuates the process of interaction but often ignores the fact that interaction is interpreted. Therefore, cognitive processes are usually not analyzed (Hautala, 2011a, pp. 55-56). Organizational learning is more than a sum of its individual parts. It is a collective activity, where meaning is shared through interaction (Cook and Yanow, 1993, p. 27). People, who create knowledge, interact with other people, objects and space (Crouch, 2010; Faulconbridge, 2010; Macpherson and Clark, 2009, p. 551). Organizations include spatial, for example, occupational boundaries integrated in the behavior of employees (Ettlinger, 2003, p. 152). Space enables (shared) learning (Faulconbridge, 2006, p. 529; Kolb and Kolb, 2005) and, therefore, knowledge is spatial.

Despite the fact that constructionist knowledge supports the idea of a spacetime, or mutually constitutive space and time, research often still treats space and time separately, as space-time. As an exception, Halford and Leonard (2006) have shown how spaces, times and discourses intertwine together as spacetime in organizations in the creation of employee subjectivity. In EG, the constructionists see knowledge as a contextual process undetached from space and time. Space can be a determining factor and a proximity matter that nurtures knowledge production (e.g. Lange and Büttner, 2010). Nevertheless, constructionism mixes with rationalist terminology. Knowledge is "produced" – a product rather than a practice (e.g. Lange and Büttner, 2010), "transferred" – reflecting the power relations between the sender and receiver (Frenkel, 2008) or "used" – rather than applied or interpreted (Weller, 2007, p. 62). In OM, the body of work connected to the "minor spatial turn" concentrates on spatial products but does not pay attention to the spatio-temporal processes resulting in such products (Beyers and Steyaert, 2012, p. 5). In the management or organization of knowledge creation, space and time are linked only partially because communicative space and relational (experienced) time cannot be simply managed (see also von Krogh et al., 2012). There is an aim to extend and create knowledge paths in time-space to avoid lock-ins into certain technology, but events are uncontrollable and lock-ins occur (Sydow et al., 2012).

2.3. *Knowledge as space with linear time*

The third perspective is knowledge as space with linear time. It considers cognitive space and is integrated to the framework of this article.

This perspective has background in psychology and cognitive sciences. It is very rare in EG and OM, but it is applied a little in STS (e.g. Bhattacharya et al., 2003; Blatt, 2009; Liu and Ma, 2013). In this view, space *is* knowledge and time is implicitly linear. Cognition (or knowing and learning) is considered distributed, situated and spatial (Seely Brown et al., 1989). According to Tversky (2009), spatial cognition can be situated on-line, when we interpret the interaction with material space. For instance, a designer might apply bright colors after a walk in the autumnal forest. The off-line situated cognition is embodied in one's ways of moving, sensing and interpreting the world. Imagination can carry people out of their bodies and world, but interpretations still originate in our situated cognition and are restricted in space and time (Tversky, 2009, p. 213). Cognition is distributed in interactions between researchers and artifacts and researchers themselves (Nersessian, 2009). Scientific laboratories are spaces that evoke and answer research questions and future paths for knowledge (Nersessian, 2006, p. 130). Scientists learn to interact with different material (laboratory) space through sequences of situated practices: seeing, moving, reacting, and manipulating (Yli-Kauhaluoma, 2006).

The "as" in the knowledge *as* space perspective refers to knowledge, space, and time as one entity. The knowledge space theory (Doignon and Falmagne, 1999) argues that knowledge is organized as a hierarchical cognitive structure to solve problems. Space includes a problem and its possible solutions. When solving problems, individuals and groups navigate in this space (Tóth and Ludányi, 2007). Skilled individuals and groups are able to explore this space in more detail and improvise in unexpected working situations (Mendonça and Wallace, 2007, p. 6). This implicitly considers spacetime. Knowledge is space and in continuous change in time. However, the possibilities of space and time, and sometimes of knowledge, are not fully employed. Some studies adopt a rationalist understanding of knowledge and turn knowledge into universal mathematical models, as utilized in the knowledge space theory. Time is not often explicitly considered, and if considered, it is seen as linear and not relational. The focus is on the cognitive dimension, while other dimensions remain untouched (Cook and Yanow, 1993; Peschl and Fundneider, 2012). Attempts to address this deficiency have resulted in stepping back from implicit space-time to explicit space-time, as space is reduced to a background container (e.g. Peschl and Fundneider, 2012, p. 49) or electronic space (McComb et al., 2010).

Nevertheless, one can call upon evolving cognitive space that also includes a relational temporal dimension in spacetime. In EG, the lack of utilizing the cognitive dimension is one reason behind the black box regarding the movement of knowledge (Malecki, 2010). Indeed, knowledge moves not only in object and communicative space, but also through cognitive spaces, or through interpretations of people and groups. Recent research indicates the possibilities for combining time and cognitive space. Groups share the understandings of tempo in their mental models (Standifer and Bluedorn, 2006). The convergence of mental models in a group is a process in linear time that includes lags (McComb et al., 2010, p. 276). The development of shared mental models in a group can

Table 1
Case study groups.

	Science (Sci)	Technology 1 (Tec1)	Technology 2 (Tec2)	Technology 3 (Tec3)
Composition by start	FiDiPro professor (P) Senior researcher (R1) Post-doc researcher (R2)	FiDiPro professor (P) PhD student (R1) MSc student (R2)	FiDiPro professor (P) Senior researcher (R1) PhD student (R2)	FiDiPro professor (P) PhD student (R1) PhD student (R2)
Cultural background	Non-Finn (P) Finn (R1, R2)	Non-Finn (P) Finn (R1, R2)	Non-Finn (P) Finn (R1, R2)	Non-Finn (P, R1) Finn (R2)
Professional orientation	Sub-field a (P) Sub-field b (R1) Sub-field b (R2)	Application (P) Theory (R1) Not decided (R2)	Academy (P) Firm applications (R1) Academy (R2)	Sub-field a (P) Sub-field b (R1) Sub-field a (R2)
FiDiPro project task	Basic research	Software application	Education, new laboratory	Tech research and application

also be seen as becoming cognitively more proximate (Hautala, 2011b). The cognitive dimension would be particularly important for advancing the knowledge-related proximity discussion in EG (e.g. Boschma, 2005; Ibert, 2010) and OM (Messeni et al., 2009).

3. Materials and methods

3.1. Main empirical material

The empirical study focuses on a narrow but important field in knowledge production, namely the academic realm, within which we present four case studies regarding four research groups. This is not to claim that academic knowledge is more important or better than knowledge created, for example, in the business sector or through indigenous practices in less developed countries. In a single article, there is not enough room for in-depth and detailed micro-level observations and discussion about many realms of knowledge. In addition, various practices in the knowledge creation processes differ when studied against different contexts.

Academia is a relevant case because it is a site of knowledge creation. The current policy context makes it even more interesting. Around the world, universities are under increasing pressure to create internationally significant knowledge with its applications for national and local economies. One tool for that has been the organization of research groups comprised of international scholars from different countries. The case in this article considers four distinguished university research groups in Finland that are linked in several ways (Table 1). Three groups operate in the field of technology (Tec1, Tec2, Tec3 groups) and one in science (Sci group). The groups consisted of researchers (R) from many countries and were led by a distinguished international non-Finnish professor (P). The Ps work and travel between two organizations in two different countries, which is why the groups are temporally dispersed. These groups were founded by a national research program to internationalize academic research in Finland. This Finland Distinguished Professor Programme (FiDiPro) was launched in 2007 when the first 24 professors started their work. The groups for this study were selected based on their location in two multidisciplinary universities quite similar in their size, geographical location and aims to internationalize. The names of the universities are not revealed for reasons of confidentiality. From these universities, four groups were selected that started their work in 2007 and were willing to participate in the study. A case study is a suitable method for studying the processes of knowledge creation in detail, especially when a theoretical framework is in a phase of development (Yin, 2003, p. 13).

Despite Finland being small in population and having few universities, it is a relevant case. In many international evaluations since the late 1990s, Finland ranks among the top countries in knowledge-based issues (Cooke et al., 2007). The smallness and "relative peripherality" of the Finnish universities – for example, the highest ranked University of Helsinki is "only" in 74th position on the Shanghai list and there are only four other Finnish universities among the top 500 (ARWU, 2011) – makes such research policy programs interesting to many countries facing similar challenges and aspirations to make a bigger impact. Applied technology-driven university research in Finland is also globally relevant, indicating how commercial outputs of knowledge creation are possible and aspired to – just to mention Nokia here.

3.2. Methods

Multiple materials and methods were applied to study the knowledge creation processes in the research groups. The main empirical material includes 120 entries in the weekly diaries written by nine research group members and 23 theme interviews with Ps and Rs from the groups (Table 2). In addition, the background material was collected through observing seven different types of research group events, such as meetings, seminars and workshops. The main role of the researcher was an "observer-as-participant" (Burgess, 1987, pp. 81–82). In this role, the researcher asked the participants questions while observing. In general, the effect of the researcher on the work of these groups was small. Some working days of the group members have been different from those when the researcher was not present, such as when they were interviewed during the workday or stopped in the corridor to exchange a few words with the researcher. The practices of knowledge creation and achievements of the groups were not affected by this.

The collection of the interview material started with theme interviews conducted separately with each research group member by one of this article's authors. The interviewees' personal and academic backgrounds were discussed extensively, along with their expectations regarding the research project under the FiDiPro program and the group work. After the first interview, the research group members started to write a weekly diary regularly submitted by email to the author. They reported the progress of their work in the research project. The diary writing ended after 6–12 months, and a second round of interviews was conducted. The themes covered the progress of the research project, the experiences of the group work in the project, and the development of the research group members' expertise during the project. Sci Rs and Tec1 Rs worked together on an almost daily basis. This is why they were also interviewed as a group on subjects such as the academic discipline, the FiDiPro project and their progress as researchers. Tec1 P was very busy during his visits to Finland. He gave only one short interview, which was followed by a longer unrecorded discussion.

The interviews were transcribed verbatim into text. The interviews and the diaries resulted in 716 transcribed pages of text. This material was analyzed using qualitative inductive content analysis, where the categories derive from the material (Elo and Kyngäs, 2007). The content or the contextual meaning of the text was revealed through systematic coding and identification of the themes and patterns (Hsieh and Shannon, 2005, p. 1278). Three phases were identified (Elo and Kyngäs, 2007, p. 110). The

Table 2
Key empirical material.

Group: members	One-on-one interview: interviewee (min)	Group interview: interviewees (min)	Diary entries: member (amount)	Observed events
Science: P, R1, R2	P (99, 43), R1 (85, 73), R2 (47, 67)	R1 and R2 (29)	R1 (9), R2 (31)	Two weekly meetings, conference
Tec1: P, R1, R2	P (15 + discussion), R1 (82, 50), R2 (65, 18)	R1 and R2 (40)	R1 (16), R2 (10)	Collaboration of R1 and R2, workshop
Tec2: P, R1, R2	P (72, 40), R1 (53, 48), R2 (71, 49)		R1 (2), R2 (9)	Workshop
Tec3: P, R1, R2	P (50, 50), R1 (93, 96), R2 (39, 42)		P (5), R1 (8), R2 (30)	Conference, course

preparation phase made sense of the whole text through careful reading. In the organizing phase, the notions of time and space were dissected and coded through words (week, software, discussion, etc.) and through the content expressing time (explaining progress, experienced time, etc.) and space (explaining routes, interactions and thinking process, etc.). For this purpose, the QSR NVivo 8 program was applied. Then, spatialities related to the time-expressing content and temporalities related to the space-expressing content were interpreted. As a result of the analysis phase, three categories of spatio-temporality were formed. In addition, the analysis regarding the cognitive space of the researchers was based on a mental mapping analysis of the material (Hautala, 2011b) built on McComb (2007). Each group was followed for about a year starting from the beginning of the projects. Being actively in contact with the research groups from the start, the authors created a trusting and relaxed atmosphere for the interviews, observation and discussions between the researcher and the researched.

The interviewees did not yet know whether they would succeed in their tasks or what kind of knowledge they would create and how. Almost all earlier research on knowledge creation has been conducted retrospectively, that is, when individuals and groups have or have not completed their tasks. Obviously, in such a case, it is difficult for individuals to recall the moments, feelings and uncertainties during the knowledge creation process. In addition, in subsequent narratives, people often create a more direct path through the project from the beginning to the key discovery or innovation. Ordinary, uncertain and failed projects are rarely addressed in studies.

4. Results

In 2007, at the beginning of their work, all four research groups aimed at a significant impact and breakthrough in their fields of research and at being actively present at various international forums. By spring 2010, all groups had published various international scientific articles as part of their results. Each group had realized something related to their specific research task, such as a database, methods, a laboratory, and specified research questions. In addition, all groups except one had increased in size (Table 3). The groups have had various communication and cooperation practices throughout time and space. For example, Sci P made frequent long (2–5 months) visits to Finland. The Sci group members had weekly meetings and they lunched together frequently, and occasionally spent free time together. They arranged two international workshops in Finland, which all group members attended. Otherwise, they did a lot of emailing between each other. Tec1 Rs shared the office and cooperated on a daily basis. Tec1 P paid short (from days to weeks) visits to Finland. Regular meetings took place during the visits. Some emails were exchanged when Tec1 P was not in Finland. In the Tec2 group, Tec2 P and Tec2 R2 visited Finland for several weeks at a time. During the visits, they had meetings with potential sponsors and prepared funding applications. Tec2 R1 did not usually attend these meetings. The project started with a rather long-lasting collection of funding. In the Tec3 group, Tec3 P visited Finland for quite long periods (several weeks to a few months), during which the group members had one-on-one meetings with P. Otherwise they communicated by email and Skype. Tec3 R1 and R2 also worked at Tec3 P's home university abroad. Three research projects (Sci, Tec2 and Tec3) continued beyond 2010.

As the key result for the first main research question – *What kind of combinations of space and time exist in the knowledge creation?* – three overlapping combinations of space and time were found (Fig. 1). We call them the time-space of the stages (A–E), the space-time of flows and disruptions (stable, unsecure and slow periods), and the spacetime of networks (important events and event bundles). Table 4 shows examples of knowledge creation in groups during linear and relational time. These examples are only analytically separable into different dimensions of space. A transcript excerpt below indicates how all dimensions of space and time exist in all knowledge-creating activity and in all the three combinations. Codes for time are LI(near) and RE(lational), and for space OBJ(ective), COM(municative) and COG(nitive). However, the analysis of the whole empirical material – over 700 pages of transcript – indicates the centrality of certain combinations of the dimensions of space and time in relation to knowledge creation processes.

> *The other day[LI] (Professor) when we met[COM] here around this table[OBJ], (Professor) had written[COM] on a piece of paper[OBJ] that "(R1) I found that there can be another analytical solution[COG], and then[LI] the paper[OBJ] was full of writing[COM]. And then[LI] there was "you check this[COG] and write[COM] it down[OBJ]." I was overwhelmed[COG/RE] by this for a month[LI], wondering[COG/RE] about the equations[OBJ], and tried to find something[COM] from the books[OBJ] that could explain[COM/COG] how this part has been progressed[LI] to that part[COG]. And there are thirty of these in a row[OBJ]. And then you think you had it[COG] until[LI] you realize[COG] that there is a minus and here[OBJ] it has been changed[COG]. Is it like this then[LI] and. Yeah, I have noticed[COG] from time to time[LI] that if you think[COG] long enough[LI] about something and try to understand the big picture[COG], then you have moments[LI] when you realize[COG/RE] how this one[OBJ] follows straight from that one[LI/OBJ], even though before[LI] you had thought of this through a giant detour[COG]. (R1, interview, January 29, 2008)*

The answer to the second main research question – *What kind of knowledge process(es) do these combinations bring out?* – is knowledge as a process of progression, of becoming distinguished, and of path-taking and bundling.

Table 3
Key achievements of the case study groups, 2007–2010.

	Science (Sci)	Technology 1 (Tec1)	Technology 2 (Tec2)	Technology 3 (Tec3)
Achievements by 2010	4 articles 3 new methods	4 articles, 2 PhDs Database	4 articles Laboratory in active use	Publications Defined research questions
Staff number in March 2010	7 (+4 persons)	6 (+3 persons)	3 (no change)	5 (+2 persons)

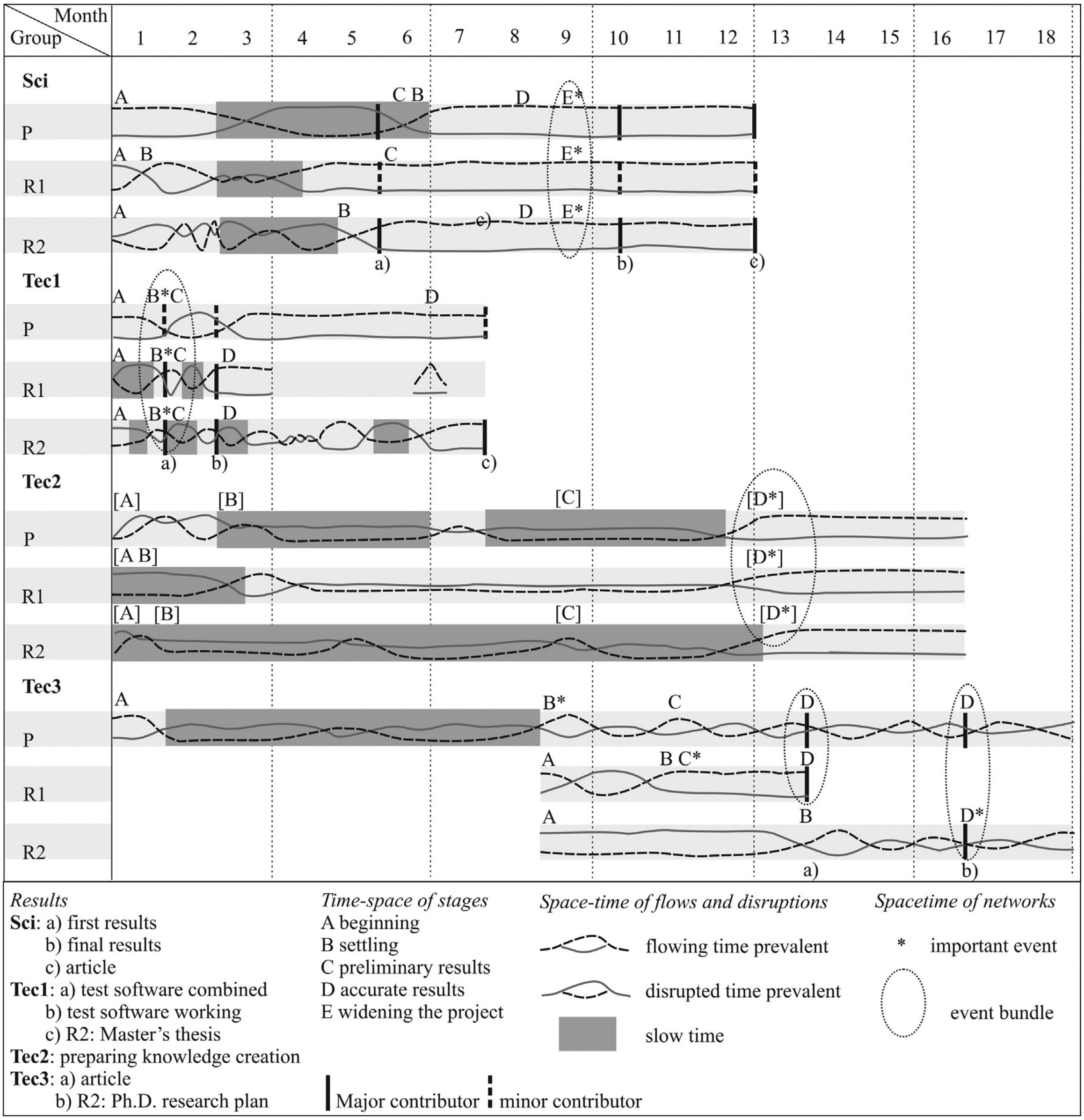

Fig. 1. Combinations of space and time in the knowledge creation of the case study groups.

4.1. *Time-space of stages: progressing knowledge*

Rs and Ps interpret the progress in knowledge creation by organizing their project into sequenced entities (periods) or stages in linear time (Fig. 1). The progress is specific for projects and their members. The (overlapping) stages might not have a clear beginning or end. The role of significant points in linear time in the form of events is common, and these points correspond to the transitions between the stages. The general stages are: the beginning (A), when the project and the work practices are starting to take shape; the more settled period (B), when the members have received relatively clear tasks and know how to proceed with them; preliminary results (C); more accurate results (D); and expanding the project (E).

The time-space of stages brings out progress in the processes of knowledge creation. Knowledge is built on top of the existing knowledge. Similarly, as a project proceeds from one stage to another, it develops the research idea incrementally into knowledge and explicit results. In contrast to "knowledge of space" perspective, knowledge is not loose of space. The stage binds space and time together: certain equipment, literature and linear time for testing and analyzing are needed to progress to another stage. Despite object space and linear time having visible roles here, the stages bind all dimensions of space and time together, which is not shown in the "knowledge of space" perspective.

"Being there" geographically and in object, communicative and cognitive spaces is important for progressing knowledge (see also Edler et al., 2011, p. 801) and binding the space and time dimensions. When the research groups work at the same university, they also share the object space, which deepens their communicative space. Communication occurs mainly face-to-face. Rs use the same routes, lunch in the same cafeteria and see the same landscape. The object space of software and other work equipment becomes active in the knowledge creation. Even when the members were in different locations, the object space was shared to some extent. Still, each group had members who thought that not being physically at the same place slowed down the knowledge creation. One reason was the lag in communication due to being located in different time zones. However, being there is not only the mutual physical existence of Rs and Ps that combines object and communicative

Table 4
Examples of knowledge creation in the groups during linear and relational times in each dimension of space.

Time/space	Object	Communicative	Cognitive
Linear	Being there (location) (P/Sci) Progress in resolving problems with software, etc. (R1/Tec1) Building a laboratory (P/Tec2) Progress in defining problem in meetings, applying blackboard to describe thinking (P/Tec3)	Event-bundles (all groups)	Continuous process of thinking and interpreting: Working all the time, too much, being a workaholic (all professors)
Relational: flowing	Applying blackboard and getting excited in meetings (P, R1 and R2/Sci) Article accepted (R1/Tec1) Laboratory starts (P, R1 and R2/Tec2) Finding the right theme for a joint article (P and R1/Tec3)	Communicating through problem-solving skills and excitement (P and R1/Sci) Intense collaboration with each other and computers (R1 and R2/Tec1,P, R1 and R2/Tec3) Communicating by teaching people to use equipment (P, R1 and R2/Tec2)	Starting to understand the new field/task (R1 and R2/Sci, R1/Tec1) Interpreting new, unexpected but exciting results (R2/Sci) Sharing interpretations: teaching new people the field (P, R1 and R2/Tec2) Finding a common understanding for a joint article (P and R1/Tec3)
Relational: slow	Not being there (location) (P, R1 and R2/Sci) Software not working correctly (R1 and R2/Tec1) Funding issues (P, R1 and R2/Tec2) Too much geographical distance (R2/Tec2) Trouble of finding the right students in the same location (P/Tec3)	Communicating with the professor through electronic means (P, R1 and R2/Sci) Lack of communication: no topics to communicate about or no people or equipment to communicate with (R1 and R2/Tec1, R1 and R2/Tec2, P/Tec3)	Challenge of interpreting a new field/information (R1 and R2/Sci, R1 and R2/Tec1) Too much cognitive distance (R1 and R2/Tec1) Frustration of not being able to take thinking forward (P, R1, R2/Tec2)
Relational: disrupted	Computers crash (R2/Sci) Software crashes (R1 and R2/Tec1) Trouble in applying new lab equipment (R2/Tec2) Disturbingly loud voices at the office (R1/Tec3)	Communicating intensely with people and objects (R2/Sci, R1 and R2/Tec2, R2/Tec2, R1/Tec3)	Disruption in interpretation process due to strange results (R2/Sci), additional tasks (R2/Tec2) or mistakes (R2/Sci, R1/Tec1, R1/Tec3)

spaces, but also the creation of common understanding in cognitive space. This can be achieved, for example, by sharing concepts or methods and learning the specific areas where the understanding differs. The following citation reveals the interconnectedness of object, communicative and cognitive spaces in creating the feeling of being there:

> *We stimulate each other when we think, when we sit together, when we are getting excited on some idea, it is very difficult to get excited in Finland, but very often these things are creating some mutual multiplicative excitement. [. . .] This you achieve with working personally with somebody. This will not [be] possible by working through electronic means of communication. That's why being here is so important. (P, Sci group, interview, March 27, 2007, emphasizes "being" in speech)*

4.2. Space-time of flows and disruptions: creating distinguished knowledge

The space-time of flows and disruptions supports knowledge creation in experienced relational time. Flowing and disrupted time fluctuate (Fig. 1 and Table 5). The periods when Ps were in Finland were described as hectic, intense and exciting by the researchers, but also interpreted as progress in knowledge creation. When flowing time was prevalent, Rs almost felt disappearing time flowing in the background, and the hours spent dwelling on work were not counted since it was very rewarding. This "flowing time" is different from the moments of flow (Csikszentmihalyi, 1997), which occur as peaks of creativity when a person focuses on a task. In addition, earlier research has found that for groups with high potentiality or collective belief that the group will be effective, the deadline pressure more likely pushes the group forward (Gevers et al., 2001, p. 217).

All research projects included time that was described as disrupted and slow. Time related to the field-specific problems Rs and Ps confronted was disrupted; such time occurred, for instance, when Rs struggled to understand new theories and fields. Such disruptions were important for knowledge creation. The slow time was associated with frustration and worry related to the project organization. In the Sci group, both slowing and disrupted time corresponded with the period right after Sci P left Finland and worked for a few months at his home university. Sci Rs were worried how they could proceed apart. Sci R2's weekly diaries included specific descriptions of disrupted time: the software they had developed crashed, equations did not work properly, and he made mistakes that an experienced scientist should not make. When the same calculation is repeated, it feels like going back in time while staying in the same place. Soon after the launch of the project, Tec1 Rs started to realize that it was not clear to them what the project was about and they felt worried. They managed to accomplish a given task, but it included several disruptions. There were difficulties in getting help with the crashing software from the experts in the field and a lack of resources, as they only had a few computers with the particular software in the building. In the Tec2 group, the lack of funding created almost overwhelmingly slow time. Tec2 Rs did not write many diary entries since there was no progress in their knowledge creation. Therefore, the curve of disrupted time is fairly low in the group (Fig. 1). In the interviews, they described their frustration in such situations. Table 5 shows how slow and disrupted times bring out frustration, anxiety and mistakes – the "dark side" that current research tends to avoid (Rehn, 2010). This dark side is important when creating distinguished knowledge, which is internationally highly valued and requires deep insight, skill, time and passion to push through the "dark side" from its creators. Creation of distinguished knowledge is the process brought about by the space-time of flows and disruption. Research is a passion for the FiDiPro professors and many FiDiPro researchers. According to the P's own words, they work "all the time", "too much" and are "workaholics". They could not tell how many hours they work in a day, since work and non-work mixed. The time spent on

Table 5
Slow, flowing and disrupted time shown by researchers' quotes.

Time	Quote
Slow time including disruptions	We were wondering about an unexpected result with (Professor). I have to analyze this more carefully and make sure it is not a mistake. It is always fun to find something new and unexpected and I wait with great interest whether there will be another similar surprise. (Sci: R2, diary 4/20/2007) I should calculate it all again and it takes time because calculating all possible cases for one unit with one processor takes about a day. This disturbed my work. (Sci: R2, diary 5/4/2007) I started to calculate a few units again on Thursday. When I returned to work on Friday morning, I noticed that the code had crashed in all calculations for some reason. I changed the parameters, but the result was the same this morning (Monday). (Sci: R2, diary 5/25/2007) This week I could not calculate much because the transformer broke on Monday. The electricity was only back for this on Thursday. This disturbed my work. (Sci: R2, diary 6/8/2007) I finally found the reason why the calculations of the code I made seem wrong. When I discovered this mistake, I felt myself stupid. How did I make such simple mistakes? (Sci: R2, diary 6/29/2007) I could add the parameters to the codes on Wednesday. Of course, I did not do this completely frictionless because at first I did not understand to change the (name). When I wondered about the peculiar results, I started to see the reason after I downloaded a code from the Journal (name). [. . .] Right now almost all the computers are processing calculations with this code. (Sci: R2, diary 7/4/2007)
Flowing time	This has been surprisingly fast. I got (an article) right after four months of collaboration into a conference in (name of a place). Then, in November I was in (name of a place) for a week. I was working day and night, which was easy and fun because otherwise I was really lost the place because I do not know the language. (Tec1: R1, interview 8/21/2008. Discusses about the PhD project after leaving the FiDiPro)
Slow time	I was nervous about how this will start and about other things, and I still am. Well, is it maybe the biggest thing I am still disappointed with? That things go forward so slowly that it feels crazy. (Tec2: R2, diary 7/11/2008) It has been quiet here for a long time, at least from my part. Things happen slowly and then a lot happens at once. [. . .] Things go forward in Finland much more slowly than we thought. (Tec2: R2, interview 1/17/2009)
Disruptions in otherwise flowing time	They used to come into our office without knocking the door. And they made our office just like a discotheque [. . .] they would come, start talking, quite loudly. Just laughing a lot and then you wouldn't be able to concentrate anymore. My case was really disturbed with that (Tec3: R1, interview 11/17/2008)

creating innovation, going beyond what is known and solving difficult problems was described with expressions indicating positive feelings. Many interviewees wanted to be known for the exceptionally good quality of the explicit results they create. They explained that top expertise, or the desire to create distinguished knowledge by finishing their results in the best possible way, comes from passion and drive:

> *Doing extra work to make the work that you do high quality. You can put this from here to there {moves a coffee mug on the table} but then if you, you know, do the last thing {knocks the mug, turns it slightly to a different angle} to do it right, to do it better than other people, to do it the best possible way, you get extra work, and extra preparation, extra formulation, extra work. And I like to do that. I like to be known for somebody who, whatever I do it is high quality. (P, Tec3 group, interview, May 29, 2007, emphasizes "known" in speech)*

> *I have deadlines, I am a high pressure person. If you want to be successful in your career, you want to work in my group. You have to take the beatings, too. It's not physical beatings, it's pushing. It's gold. If you push gold on fire that's how it becomes gold. (P, Tec2 group, interview June 19, 2007)*

Current knowledge creation literature applies relational time in the "knowledge in space" perspective. In this perspective, cognitive space is not considered relevant. In contrast, the relationship between space-time of flows and disruptions with the cognitive space is interesting, although objective and communicative spaces also exist here. Learning a new field, skills and theories in disrupted time is important for becoming cognitively proximate. "Cognitive proximity" means here a common understanding created through shared concepts and aims of the knowledge-creating project (Hautala, 2011b). In the Sci and the Tec1 groups, the slow time was associated with the cognitive distance of the members' knowledge bases. Creating a common understanding in the Sci group slowed down when they worked at different universities. When Sci P described this in the interview, he explained "distance" to be not only geographical but also cognitive when stating that the Sci Rs needed to learn the field. This knowledge was required for a smoothly progressing project and creating distinguished knowledge despite Sci Rs working in different geographical locations. Tec1 Rs felt time slowing down when they realized that their knowledge bases were cognitively distant from Tec1 P. In addition, they felt that it would be challenging to create a common understanding in such a situation. Tec3 P felt the time slowing down, because he was unable to widen the cognitive space of the project through new Tec3 Rs. For him, it was important to formulate a clear and detailed research problem, which required the combination of views of several researchers. These shared arenas of cognitive space generate a shared research project and a feeling of belonging to the group. As a result, the Tec3 Rs become attached to their project and each other.

4.3. Spacetime of network: path-taking and bundling knowledge

The third context of knowledge creation is the spacetime of network. Time and space are mutually constitutive and not analytically separable. Time is linear and relational: experienced, folded and networked. For example, an article published several decades ago might become important for a research project. The article is written in a certain (past) context, interpreted and applied in the "now" in order to get somewhere "ahead" in the future, which connects points in time into a network. Actually, the FiDiPro research projects did not "start" in 2007, since their roots can be traced back to Ps' earlier collaborations. The FiDiPro research projects will not "end" either, since the knowledge the research groups create is once and again interpreted, applied and contested in the epistemic community. In addition, the group members have enhanced their knowledge bases, which they will apply later in their research career.

In describing such spacetime of networks, it is appropriate to use concepts of nodes, bundles and path creating, which are familiar, for example, from Hägerstrand (1970). Knowledge is shown as a complex network of nodes (e.g. artifacts, people, theories, ideas, and concepts). Each node becomes interpreted through the research project and its members, which renew them. Some nodes have been changed and some added by the new methods and publications created by the FiDiPro groups. These nodes become connected in the communicative space and the knowledge-creating activity, as Tec2 P describes:

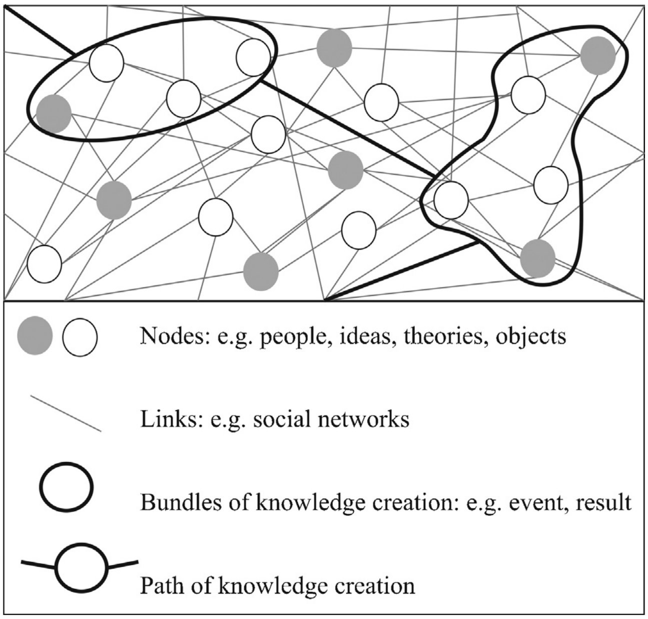

Fig. 2. Spacetime of knowledge creation.

> *Students are one, [that] make you an expert. Having good labs, just another thing that you can test your idea and see if it works, then you learn more and become an expert in that area more and more. So it's a combination of things like laboratories, having funding to pursue your ideas, so that you become an expert and having the right group of people. Smart students, dedicated, post docs, and having encouraging and supportive administration. That all adds to your expertise. And then building this network, international network with industry with other universities. Changing what we call the blood. That's what makes you an average better expert who's here working eternally forever. (P, Tec2 group, interview June 19, 2007, emphasizes "blood" in speech)*

The processes of knowledge brought out in this spacetime are path creating and bundling. These processes push knowledge toward the not-yet-known. Knowledge creation takes paths in the network and "collects" certain nodes into bundles (Fig. 2). Therefore, this spacetime brings out knowledge as a network. The meaningful combinations of object, communicative and cognitive spaces make a difference in time. This difference, the creation of knowledge, is a change that makes the time visible. The bundles might become stages of the project (see Fig. 1; the bundles were also interpreted as transitions between stages). Each research group member had their own interpretation of the aim and nodes, which is why they could find different paths and bundles to get there.

The details of the spacetime of the knowledge networks are considered through the most important event bundles of the FiDiPro research projects. The Sci group's bundle is a workshop held in a hotel in the wilderness in Finland. Almost all globally important researchers ("nodes") of the field attended it. They spent a weekend in the hotel presenting and discussing research, walking on the beach, having drinks, sitting in the sauna and swimming. The meeting was referred to as "workshop" since a relaxed atmosphere was intended and achieved. The attendees got to know the FiDiPro project, which itself became a visible node in the knowledge network. They made certain nodes (people, articles and ideas) in their knowledge network visible, as they discussed the bundles and paths to be taken to advance knowledge for the needs of both the FiDiPro project and the epistemic community.

Tec1 group's bundle is an example, which Tec1 Rs accomplished together. This required the combination of two software applications. Some of the required software was located on university computers. Therefore, Tec1 R2 had to work in a classroom. The task proved to be tricky, and the only experts who could help Tec1 Rs worked abroad. However, they managed to get help from a professor who came to give a lecture at their university. Tec1 R1 wrote in his diary that he started to see that combining two software applications opened up many new possibilities. He started to see the field's network of knowledge more widely. The developing bundle of the project became clearer. Still, after the professor's help, the Tec1 Rs had to solve a series of problems to get the software to work through learning-by-doing, reading articles and discussing with other scholars. Solving the problems bounded nodes of people, articles and software into a bundle, which in turn opened up new paths to reach the aim of the research project.

After one year's hard work, the Tec2 group received notable funding. This was their bundle, which combined the nodes of people working in both the public sector and private firms, devices and material space for the laboratory, and the idea of the research project that they "sold" to the funders and the epistemic community. The bundle enabled knowledge creation to begin. The laboratory became reality and the Finnish research group members traveled to Tec2 P's home university abroad to begin their training.

Both stages of the Tec3 group's tasks, where preliminary results were accomplished, are bundles. The first was an article written by Tec3 R1 and Tec3 P. The first topic failed since they were unable to form a common view in a shared cognitive space. They are experts in different fields and therefore have different networks of knowledge. The first topic could not combine the nodes of people, articles and ideas into the same bundle. After realizing this, Tec3 R1 completed the first article by himself and found another topic through which they were able to combine their knowledge networks and work in shared space-times. The second bundle of the research project is a clarification of Tec3 R2's doctoral thesis topic that binds together nodes of ideas, articles and software. It was clarified through several discussions with Tec3 P, explaining ideas to him on the blackboard, sketching equations and testing them with software, and reading the articles that Tec3 P recommended.

5. Conclusions and discussion

In this article, knowledge creation was studied through a spatio-temporal framework. This framework combines dimensions of space and time that were identified from the current research considering knowledge, space and time. The dimensions of space include object space of material environment, communicative space of interactions between individuals and between an individual and object(s), and cognitive space of interpretations of the interaction. The dimensions of time comprise linear time of clocks and calendars and relational time of experienced linear time.

This framework deviates positively from the overly narrow main approaches to knowledge in the current EG, OM and STS literature. In general, in earlier research all these dimensions of space and time are not considered simultaneously and explicitly. In particular, the novelty of our spatio-temporal framework is highlighted by comparing it to the three main current approaches. The first and dominating approach in the current research is knowledge of space with linear time (see Section 2.1). It focuses on predictable, calculable and explicit rational knowledge and does not pay proper attention to other dimensions of space than the material. However, our framework, based on constructionist-cognitive knowledge, highlights that knowledge exists in the explicit-tacit continuum and is created in interaction and interpretation processes. This knowledge is spatio-temporal, in other words, unconnectable from spaces and times. The second approach in the current research is knowledge in space with linear/relational time (see Section 2.2). It is the only approach taking relational time into account and it also considers spatiality of knowledge. However, it focuses only on the spatial results and not enough on their process through interaction and interpretation. Our framework is designed for analyzing the processes of knowledge creation, interaction and interpretation. The third approach in the current research is knowledge as space with linear time (see Section 2.3). It is still a loose and thin collection of studies based most often on psychology. These acknowledge cognitive space, but connect it only to linear time and often narrowly to rationalist understanding of knowledge. Through our framework, cognitive space is also combined with relational time. Therefore, the understanding of knowledge is more complex and comprehensive.

This article makes two major contributions to the current research on knowledge creation. First, EG, OM and STS have shortcomings in understanding the complexity and comprehensiveness of knowledge (creation). Our novel spatio-temporal framework helps face these challenges moving forward from overly limited rationalist and constructionist views toward knowledge as interpreted and as a spatio-temporal process. As indicated by our empirical results, knowledge processes include step-by-step progress through stages, being passionate and pushing individuals and groups through flows, disruptions and slow times toward creating distinguished and contested knowledge, and bundling and widening the knowledge network toward the not-yet-known. To achieve explicit research results, researchers go through the spatio-temporal processes of stages, flows, disruptions and bundles. The complexity of knowledge is shown more properly when various dimensions of space and time are acknowledged. Linear time and object space become visible in the time-space of stages, cognitive space and relational time have important roles in the space-time of flows and disruptions, and all dimensions of spaces and times are connected in the space-time of networks.

Second, our approach challenges the current research that focuses empirically on the overly narrow and limited variety of dimensions of the knowledge creation processes. Our framework brings out the common “dark side” of difficulties, unexpected events, disruptions and slow times that is usually avoided in empirical knowledge creation research (Rehn, 2010). According to our results, such difficulties are connected especially to cognitive space and relational time, and this is highlighted in our empirical results. Even though the progression of knowledge in object space and linear time has already been acknowledged, this strand of research tends to see knowledge loose of space (see Section 2.1). However, our findings suggest that explaining the progress of knowledge also requires dimensions other than object space. Being there in the material space, which is important for progress, is also being in cognitive and communicative spaces.

The varieties of the movement of knowledge are not yet well known in EG, partly due to its emphasis on the rational view for knowledge. Analyzing the process, in this case movement, requires considering time. In EG, time is mainly linear “past” and seldom explicitly considered. When collecting empirical materials from events that have already taken place, time is mostly treated as “past”. We show how the movement of knowledge is not restricted to the start and end points in linear time, but it is a process in between and beyond them. Past and future come together in bundles in “the now”. The movement of knowledge is not restricted only to locations and interactions, but it also changes in interpretations in cognitive space. We show how group members experience time and interpret knowledge differently, and how this variety provides alternative paths for forwarding their projects. This article also adds to the proximity discussion in EG and OM. Due to its detachment from groups and individuals and its rational approach to knowledge, cognitive proximity has been very little studied as a process (Hautala, 2011b). In this study, we show how cognitive proximity research also benefits from the consideration of relational time. The group members considered time to be slow when the cognitive distance between the group members was realized. In addition, cognitive space is essential for studying cognitive proximity.

The limitations of this research are mainly due to empirical study of limited scope. We analyzed only four groups that create scientific and technological knowledge within one knowledge realm, namely the academic realm. The groups were analyzed in their early stage for about a year, when they were just bringing about practices for working together. The method is designed to analyze the knowledge creation processes at several points in linear time. Following the groups from the early stage is actually also an advantage, since the work in many organizations means the constant formation of new groups around changing projects. Often the beginning stage is sensitive and therefore important for creating high-achieving groups.

Implications for universities and managers can be identified from this article. The academic world and university administrations often base their respective rankings and strategies on the rational measurable and predictable knowledge that exists in linear time. We show that such understanding of knowledge leaves much of the creation process untouched. When the aim is to create distinguished knowledge, unpredictability and disruptions in relational time need to be addressed as well. The development of globally successful research groups is challenging. It is not enough just to invite and fund distinguished scholars to form their research groups. It is as much about how scholars and researchers and the academic and administrative environment interact. Complex knowledge creation processes cannot be fully governed, but administration and managers can create opportunities for the formation of diverse bundles of previous work, infrastructure and different researchers. The more bundles a group can see, the more paths they can imagine for knowledge creation, and the more likely they are able to work through slow time and disruptions. The managers can potentially enhance knowledge creation by forming groups of individuals with varying backgrounds and dismantling the administrative obstacles that hinder the formation of common understanding between the research group members.

In the future, research regarding the knowledge creation processes, individuals and groups should be monitored over several years to trace how knowledge advances and gets distributed spatio-temporally over long periods. The spatio-temporal framework should also be applied in various other knowledge realms, including art, business and local communities. One specific result to be researched further is the shared context, for example the shared interpretations of space and relational time at specific moments and periods (see Fig. 1).

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