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Sources of scientific creativity: participant observation of a public research institute in Korea

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Abstract

This study aims to find the factors of scientists' creative thoughts by observing directly their laboratories in Korea Research Institute of Chemical Technology (KRICT). The participant observation was performed for 5 months from December 2013 through April 2014, and the research object was the lab which had been selected both as Top KRICT laboratory and Top National R&D Project. For in-depth examination, the target lab was supposed to be observed for a long time, taking part in the lab meetings, interviewing the researchers. From the interview data, Protocol analysis or Verbal data analysis was employed to analyze the recorded data. The research results are as follows. First, as several studies had suggested, the frequent use of analogies was verified as an important source for scientists' creative thoughts, in that those analogies were used for 12 times in 2 lab meetings, which was 6 times per each. Secondly, the frequent appearance of unexpected findings was found, that is, 8 out of 15 experiment findings were unexpected. We found that the scientists pay close attention to the unexpected findings in that 67 out of 88 intra-group interactions were about the unexpected findings, and 21 out of 24 individual reasoningblocks were about the unexpected findings. Finally, we found that the seeds of new knowledge and ideas sprouted and spread through the distributed reasoning process, which is the major characteristic of modern science that is generally conducted by group of scientists. The findings have two theoretical implications. First, it may increase the availability of Ikujiro Nonaka's knowledge-creation model by adding another case study. It may also contribute to balance between supply-side and demand-side perspective of Innovation. System studies by supplementing supply-side perspective.

Introduction

Innovative system is defined as the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies. (Freeman, 1987; OECD, 1997) Such a perspective, regarding innovation as a certain system, emerged as a retroaction against the previous linear-model of innovation. The famous report of Vannevar Bush (1945) is just the archetype of such a linear model, and which shows the conceptual image of process from basic research to the economic growth linearly. Since the advent of the systematic perspective, still, many scientists in laboratories believe that the science policy should be in accordance with the Bush's suggestion.

By mid-1980s, some change began to occur in such a trend. From the Kline & Rosenberg's (1986) chain-linked model as a start to Ralph Gomory's (1989) circle model, a group of scholars insisted that all stages from the basic research to the product development are closely intertwined, that is to say, non-linear model of innovation system. Christopher Freeman demonstrated, later, in his theory of National Innovation System, that innovation is not simply a linear or naturally spontaneous process, but it may happen through institutionally established system by government involvement (Freeman, 1987). Now, the government's active involvement became important that help creating an environment for innovation. The innovation studies in 1990s' such as Lundvall (1992), Nelson (1993), Edquist (1997) were followed by this, and Organization for Economic Cooperation and Development (OECD) has introduced the approach to its member states rapidly to increase the science and technology capabilities of each country.

However, recent theories of national innovation systems are criticized for couple of reasons. One of the reasons is that the level of analysis is too large. Based on the macro perspective, like the regional, industrial, technological or national level, they can hardly capture the very moment of innovation which is created in the level of individuals and laboratories. Although some scholars have made contribution to fill a gap between them, such as between NIS and open innovation in a firm-level, many theories still have limitation in terms of explaining the micro-level innovations, and which became the motivation to this study for disclosing the mechanism of creativity in the laboratories (Jeon et al., 2015; Yun, 2015).

Another research background originated from the question of innovation theories based on the demand-side perspective, such as the social problem-solving R&D and 4th generation R&D, based on Mode II theory and technology management theory respectively. Mode II laid the methodological and theoretical foundation for solving the social issues, emphasizing S&T social responsibility (Gibbons et al. 1994, Nowotny et al. 2001). The 4th generation R&D theory, as a subfield of the classical theory in technology management study, put emphasis on the marketability and profitability.

Then, can't we say all the scientific knowledge and technologies, which is unmarketable, profitless and socially worthless for the present, as innovation? Considering the history of science that numerous breakthroughs were not accepted in their own age but recognized in later generations, a question arises as to the validity of the R&D management and its generalization. Thus, we doubted if the demand-side approaches apply to all of the cases, and have focused on scientific creativity as a complementary approach to them.

Where there is innovation, there is creation. As we study more deeply about the innovation, we come to know that a creative person matters, because the innovations are originated out of a particular person's idea ultimately. Although there are institutional frameworks like laws, budget and regulations, the fundamental role that create such innovations within those policies belongs to men. Therefore, we also need to pay attention to the studies of creative people themselves. This is where and how this study based on the micro perspective can contribute to the field.

Creativity has a significant meaning economically as well. On the one hand, the conceptual study of Carrillo (2015) on the evolution of knowledge-based economy indicates a coming new economic era, on the other hand, creative knowledge is important economically in the aspect of quality of research activities as well. Unlike the

Management of Technology (MOT) emphasizing the market competitiveness, creativity study is as economic a perspective as the MOT in that it emphasizes the efficiency of R&D investment. Why do some organizations achieve better results while others do not, even if they get the same budget and support from the government? All of the organizations would be different despite receiving the exact same amount of budget. We can infer that the member researcher's capability determines a lot of things.

Considering the economic development stage of Korea, switching from Fast-Follower to First-Mover, the need for a careful study of creativity is crucial. As Korea government pays more attention to the R&D investment efficiency unlike in the past, the importance of the creativity study is greatly increasing. The Science and Technology Policy (STP) and MOT field, therefore, need to study in depth of related academic areas such as phycology, to say nothing of the various issues like individual/organizational creativity and the relationship between creativity and innovation.

Literature review

The four classifications

Studies on creativity of small groups and individuals made significant progress in America thorough 1990's, Teresa M. Amabile was a representative scholar during this period. Those earlier works, including the Amabile, focused mainly their researches on small organizations within corporate environment. Amabile (1988) described the mechanism of small group creativity as a person-organization feedback system in the detail, and it was found that the factors like task motivations, knowledge, skills and one's will act as important variables in terms of individual creativity, while the factors like resources, management system and organizational culture were significant in the organizational level.

Kevin N. Dunbar is another creativity scholar, well-known for his study on the sources of scientific creativity in the laboratory level. He belongs to the Cognitive Psychology school that is followed by Amabile, Sternberg & Lubart (1995) and Simonton (2004), but more unique in the fact that he focused more on the so called Wet Lab[1] (almost pure sciences), compared to the others (Heinze et al., 2009; Sternberg & Lubart, 1995; Simonton, 2004). Some scholars have noticed the promotion of collaborative capacity including advanced creativity, new ideas arising, knowledge, other view of life, inter-generational awareness through the open innovation, from the context of micro perspective such as individual level (Oganisjana, 2015).

He pointed out that it is appropriate to study creativity at a group level, as modern science is mainly performed by cooperation of several scientists in a lab, so participant observation of such a lab environment is efficient to capture the mechanism and original sources of creative process. We, thus, decided to apply Dunbar's methodology to the study, as a suitable model for participation observation (Dunbar, 1995; 1997).

Kim (2008) classified the existing studies of scientific creativity into 4 categories in Table 1, and we tried to verify where Dunbar's study and ours fall under. The first category is a school focusing on the certain outcomes, developing methods of assessing the creative results. The second is a school which put emphasis on a creative person. The scholars have been keeping their interest on the relationships between intelligence and various human traits like personality, age, and etc. The third school has focused on

Table 1 Different Perspectives of Creativity Studies

Focal Point	Description
Creative outcomes	• Studies on the quality and the degree of the creative results • Interested in measuring the novelty, usefulness, and attractiveness
Creative individuals	• Studies on the creative person • Interested in the relationship between personality, age and intelligence
Creative process	• Studies on the development process of creativity • Interested in the process of problem-solving, associations, convergent/divergent thinking
Creative environment	• Studies on the environmental factors influencing the creativity • Interested in the institutional and administrative factors.

the development process and stages of creative ideas. Lastly, there is a school of creative knowledge environment, suggesting that the institutional environment of organizations matters. Dunbar's study, among the categories above, belongs to the third one (creative process school), and so does ours.

Dunbar's research

The purpose of his research was to capture the moment in creativity and answer the various questions about the scientific creativity by explaining the mechanism, which is a key to establish a strategy to promote creative thinking in the field.

He chose the molecular biology laboratories as a research object. He believed that the molecular biology was ideal because it is the most innovative area among the modern sciences, which had been passing through the age of great discovery. The four target laboratories were all led by world-renowned researchers in one of the top American universities. Participant observation with recording the 'real-time' lab meetings had been performed, considering the memory loss of interview method, which makes it possible to capture the flow of new ideas.

The results found three sources of scientific creativity. Firstly, analogical reasoning is very important. Scientists used to explain a new phenomenon, by analogy with other concepts, which was very frequent in all of the laboratories.

Apart from the analogy, the scientists' particular reactions to anomalies were unique, compared to the ordinary people, and played an important role in overcoming a confirmation bias. Scientists tend to think alternative pathways actively to the existing phenomena, and this was a major driving force for discoveries.

Thirdly, distributed reasoning, or a critical groupthink, played an important role too. Scientists shaped new ideas and concepts collectively through intense and free discussions, regardless of their status. Groups of scientists can make achievements that individuals can not make. Dunbar described such a cognitive process as a collective 'tinkering', the accumulated small accomplishments leading to the large accomplishments, which is a simple truth that gives significant implications to the existing theories on innovation system mainly focusing on the macro and institutional objects.

Our study was performed mainly based on the comparison with Dunbar, because the molecular biology and chemistry are similar in that both are a field of study usually performed in the laboratory as a group (not like mathematics where a scientist alone immerse himself in the office silently). Furthermore, we chose KRICT, where we belong to, as the subject of case study for ease of observation.

Research subjects and methods

Research subjects

To investigate the sources of scientific creativity, or to verify Dunbar's study in part, we applied his framework to the case study of KRICT as Table 2. A laboratory (Lab A) was selected by a certain standard for this and we attended regular lab meetings from December 2013 to April 2014. The 'Lab A' collaborated with a research team of the University S, where the researcher A led the Lab A and the professor B led the latter respectively. The joint research team focused on the application of the 'Promotion of Atomic Layer Deposition (ALD) on Metal-Organic Frameworks (MOF)'. It was consist of six researchers, the two joint lead researchers, one senior researcher, and three doctoral students. The research was mainly conducted by the doctoral student C, thus the student researcher C was supposed to be the first author of the paper when published.

Two regular lab meetings were closely observed on 20th Dec, 2013 and 19th March, 2014, and five interviews with student researcher C were performed on the following dates: 12/30/2013, 1/13/2014, 1/20/2014, 1/21/2014, 3/10/2014.

Data were collected through the audio recordings of each lab meetings, and they were transcribed for protocol analysis. Additional interviews, grant proposals, experiment results and presentation materials were also used as supplementary data. As the project was considered to be at the end of their research plan, a paper is currently expected to be submitted to some prestigious scientific journals in chemistry field such as *Angewandte Chemie* and *Chemical Communications*.

Methods of data collection and data analysis

For the data collection, Participant Observation method was selected to compare with Dunbar, which is one of the well-known qualitative methods in the field. As the observation method has its strength in capturing moments of the thinking process in real-time basis, it is preferred over other methods such as interviews, because the interview method has inherently the limitation of memory loss in the course of tracing human memories back.

Because the ability for the interviewee to trace back their thought process in an orderly manner is very limited in such a complicated setting like the lab meetings where the multiple feedbacks and interactions occur, it is considered to be more effective to observe the meetings closely and directly on the spot for capturing the creation moments than the ex-post interviews and ex-post analysis of research notes or research papers.

Seed ideas are not developed into concrete plans straight away, and it usually takes time. For example, some ideas may emerge at an early age of a project and quickly disappears into the researcher's long-term memory in hiding, until a certain 'retrieval cue'

Table 2 A Comparison with The Existing Research

	K. Dunbar	YS. Jang
Field and Subject	Molecular biology - 4 labs (Control of cell differentiation, Control of bacterial traits, DNA-RNA of parasites, Infiltration mechanism of HIV)	Chemistry - 1 lab (MOF-ALD)
Period	One year	5 months

brings them to one's conscious awareness. This is why the participant observation of the 'on-line' lab-meetings is more efficient for tracing the flow of scientific thinking.

There have been two lab meetings during the period of participant observation for 5 months. We analyzed the collected data through the Protocol Analysis method as Dunbar did in his research, which is a well-known research method in cognitive psychology field, and it helps mapping the subjects' thought process by coding and analyzing verbal data (Ericsson & Simon, 1993; Ericsson, 2006).

In this study, the final unit of analysis is a body of statements after the transcriptional process, from the scientists' primitive utterances. During the process, all of the spoken words were split into the similar semantic units, which are called 'language corpora'.

Results of case study in krict

Analogy

It is found that there are two types of analogies working. One is to draw an analogy from other similar researches in the field, and the other is to remember his own research results what was done in the past. Thus, the first type can be said as "Looking Around" and the second analogy can be said as "Looking Back".

Frequency of analogies

In total, 12 analogies were drawn during the 2 lab meetings throughout the period. Half of the analogies were from the first lab meeting, and the rest of 6 analogies were from the second meeting. In the case of Dunbar, the number of analogies of each meeting varied between 2 and 14 times (6.1 on average), which is said to be frequent as in Table 3. Therefore, we concluded that scientists use the method of analogy or metaphor very frequently in KRICT case as well.

Categories of analogies

Dunbar classified the analogies into several categories based on its purpose and 'distance'. Based on its distance, which indicates the distance between analogical base and the target, the analogies in his case study were classified into the following three categories: (1) Within organism (2) Other organism (3) Non-biological analogy.[2] He categorized and described the three cases in detail following the classification criteria.

First, he introduced a HIV research team as the example of 'Within organism' category, where the scientists tried to disclose the mechanism of HIV virus in-vivo context by using the analogy of related in-vitro HIV field. Secondly, in the case of 'Other organism', scientists focused on the differences between Ebola and Herpes to explain a various aspects of Ebola. Thirdly, as the 'Non-biological analogy', he introduced a group of scientists who liken the chance of polymerase chain reactions to the possibility that a trained monkey can type the novel of Shakespeare.

In this study, we categorized the analogical reasoning emerged from the meetings into three types with the distance, after considering that the purpose of the Lab A was

Table 3 Frequency of Analogical Reasonings

	K. Dunbar	YS. Jang
Frequency	99 times during 16 meetings/ 2 to 14 times per each meeting (6.1 on average)	More than 12 times during 2 meetings/ 6 times per each meeting on average

to succeed in developing ALD technique on MOF: (1) ALD-MOF analogy (All of the analogical statements concerning the MOF compounds and ALD techniques), (2) Neighboring field analogy (The related concepts of neighboring field, not direct statements of MOF-ALD. For example, a certain concepts from the more general field of chemistry), (3) Non-chemistry analogy (Ideas beyond the chemistry field, such as biological metaphor)

We also investigated if the distant analogies appear frequently or not to verify the long belief of related academic community that the major and small discoveries in science history had been mainly based on the distant analogies.

In the study, the non-chemistry analogy was not used in all of the cases, while the 12 analogies were all categorized into either ALD-MOF or Neighboring field, indicating that almost analogical reasoning emerges from the place not beyond the realm of chemical science. The result is in accordance with the study of Dunbar. Therefore, it seems hard to find the evidence for the famous examples of analogy in science history such as Rutherford's atom-solar system and Kekule's benzene-snake metaphor in real laboratory environment.

By its purposes, the analogical reasoning is classified into four categories as follows as in Table 4: (1) Hypothesis generation (2) Design of Experiment (3) Fixing experiment (4) Explanation of ideas. In the study, it was found that the half of the analogies was for designing experiment, and the others were either hypothesis generation or explanation of ideas respectively, and the result shows a noticeable difference with the American case of Dunbar where almost half of the analogies was used for explaining ideas.

Such result seems to stem from the difference of the research period and stage between them. The project of Lab A was in the early stage of its total research plan, as we performed only for 5 months from the beginning (while one year in Dunbar), and thus they had to spend most of time to set research direction and to design experiment during the period.

Inquiring mind to the unexpected findings

Confirmation bias

Now let's take a closer look at a psychological experiment (2-4-6) and a concept, confirmation bias. The well-known psychological experiment, which is related to the concept of confirmation bias, starts with researchers showing 3 cards numbered with 2, 4, 6 respectively to the experiment subjects. The subjects are informed that there are specific rules in the arrangements of the numbers and they are asked to give a correct rule

Table 4 Categories of analogical reasoning in this study

Distance Goal	(Close) MOF-ALD	Neighboring field	(Distant) Non-chemistry
Hypothesis generation	1	2	3
Experiment Design	4	2	6
Fixing experiment	-	-	-
Explanation		1	3
Total	7	5	12

behind those numbers back to the researchers. They can test as many possible answers as they want to try by showing their 3 hypothetic card sets, and then they are supposed to get feedbacks from the researchers whether the each set is correspond with the rule. In other words, they can try every possible card sets, but they have only one chance to answer the rule. Since the chance of giving the answer is limited to one time, they should consider a range of possibilities and test various combinations of numbers thoroughly.

Most participants answered that the rule is a multiple of 2 or an even number as many people might expect. Combinations such as 4-6-8 or 20-22-24 were usually suggested and the researchers gave them "yes" answers in the test stage. With the affirmative responses after several trials, the participants used to be assuring their rule as a correct answer and delivered their final answer to the researchers.

However, few people succeeded in getting the right answer. The reason is, contrary to popular expectations, the correct answer was simply increasing numbers which means three numbers increasing by one in ascending order. It had nothing to do with even numbers, multiples of 2, multiples of 3 and etc. As long as the number was increasing in ascending order, any randomly arranged numbers were fine.

The results naturally raise an intriguing question that why it is very difficult for the most participants to find such a simple answer. Psychologists answer: confirmation bias of human being matters. Cognitive bias is a possible reason to explain such tendency. That is, people tend to select only the evidences which confirm their original hypotheses. For example, those who had supposed multiples of 2 didn't try to investigate other scenarios like multiples of 3 or 4, while those who had believed even numbers didn't test cases of odd numbers. This suggests that the participants have a certain cognitive bias of selecting evidences by accepting only the facts supporting what they want to see. It is not easy for the people to recognize and overcome their own errors by themselves.

To the general public this phenomenon is not too much of problem and it's just a small psychological experiment at best, but it's a different story in science laboratories. Such a tendency could cause a serious problem in science field.

How do scientists respond to the unexpected findings?

Another issue is the unexpected findings with regard to the confirmation bias. Dunbar has introduced the specific tradition of science community, paying attention to the unexpected findings in experiment rather than ignore them. This specific attitude seems quite different from the confirmation bias discussed above. Therefore we tried to verify how scientists respond to such unexpected outcomes and overcome the confirmation bias in the study.

Above all, we classified the results of experiments in the lab into three which are expected findings, exploratory findings and unexpected findings. Expected findings were the results which corresponded with the initial hypotheses and expectations of researchers in the lab. Exploratory findings came from the experiments without any hypotheses. On the contrary, unexpected findings were the cases where deviating results were generated compared to the original predictions based on hypotheses.

As shown in Table 5, there were fifteen findings in total from the two lab meetings in which eight were unexpected findings and seven were exploratory findings, but the expected findings were not found in the study. It seems to be related to the exploratory

Table 5 Frequency of Unexpected Findings

Types of Findings	Frequency
Unexpected Findings	8
Expected Findings	-
Exploratory Findings	7
Total	15

characteristic of the project performed by Lab A. One interviewee said that the technology about ALD on MOF is a new frontier and this can probably affect the result. Further research is much needed to verify whether the exploratory characteristic of an experiment interrelates with the low frequency of the expected findings.

We analyzed the statements of scientists in lab meetings to examine their responses toward the findings. At first, the statements were split into different verbal blocks by their semantic similarity. Such a unit composed of same verbal blocks was called a reasoning-block. With the frequencies of reasoning-blocks, we were able to estimate how much scientists pay attention to each finding. The higher the frequency, the more the scientists focused on that matter.

It is found that there are two different reasoning-blocks. One is usually suggested by the substantive experimenter who performed majority of the project (The doctoral student 'K' in the study). The other is collective reasoning-blocks made by lab members together through various interactions among themselves with respect to the suggestions from the doctoral student. We call these collective reasoning-blocks as 'group interactions', in that the rest of the lab members used to respond to the reasoning-blocks of the substantive experimenter with simple talks, heated debates and brain storming among them.

When we counted the reasoning-blocks of the substantive experimenter (doctoral student K), we found that he paid much more attention to the unexpected findings (twenty one reasoning-blocks) compared to the expected findings (none) or the exploratory findings (three reasoning-blocks) based on the amount of interactions and discussions they had during the lab meetings.

Interestingly, they responded differently to the unexpected results in two ways. Either they regarded the findings as just experiment errors and tried to explain the causes or find solutions (Erroneous reasoning), or believed the results as something unknown and tried to find a new way to explain the phenomenon (Explanatory reasoning). To put it concretely, of the twenty one reasoning-blocks to the unexpected findings, eight were erroneous reasoning and thirteen were explanatory reasoning. While in the exploratory findings all the 3 reasoning-blocks were categorized into the explanatory reasoning.

This result is quite different with the study of Dunbar where the explanatory reasoning comprised majority of the responses, thus more research is needed to explain the differences and find causes such as cultural factors. Such a difference carries an important meaning. That's because great discoveries in science history often made during an investigation into the unusual results and actively questioning mind of scientists played an important role in the process rather than the hasty conclusions of negative mind. The academic frontier spirit help bring more opportunities for the new discoveries.

One interviewee pointed out that such difference probably due to a distinctive characteristic of universities and public research institutes. Because the public research institutes require their researchers to reach a certain target within a tightly restricted time, unexpected results tend to be ignored or eliminated. It is difficult to cast a new light on the findings from a different perspective, not to mention the causes of the results for rapid goal achievement. On the contrary, research directions in universities are less strict and academic freedom is strongly guaranteed, where the creative thinking bursts more easily. Nho (2016) address this issue in terms of research ethics which makes different culture and value system in each country such as South Korea and United States. In a relatively closed environment for active debates in Korea, the dynamic knowledge exchange is unlikely to be successful.

Although the further studies are necessary to explain these issues, it seems obvious that the unexpected findings are a frequent phenomenon occurring in the laboratory. Besides, it is found that scientists are well aware of the unexpected research findings and pay attention to them, with high frequency of reasoning-blocks.

Next, we counted the group interactions made by the rest of the lab members as shown in Table 6. The number of group interactions was as follows: zero reasoning-blocks to the expected findings (0), sixty seven to the unexpected findings (67), and twenty one to the exploratory findings (21). Much more collective interactions or reasoning-blocks were also found to be about the unexpected findings here, which is almost three times more than the exploratory findings. The result, showing how much a group of scientists does pay attention to the unexpected findings, suggests that a group also does not ignore such an abnormal phenomenon and made various inferences on them.

Distributed reasoning

In the experiments of ALD on MOFs, the doctoral student K presented five research outcomes and related reasoning during the two lab meetings. As shown in Table 7, eight types of reasoning were suggested by the substantive experimenter, and the lab members discussed seven suggestions among these. Several interactive discussions among the lab members led to one agreed conclusion, three logically expanded reasoning, and three partially modified reasoning from the original suggestions. However, there was no discarded reasoning unlike Dunbar.

Such a ‘distributed’ reasoning about research outcomes among the members is a characteristic of modern science and this has the merit of supplementing the

Table 6 Frequency of individual reasoning-blocks[a] and group interactions[b]

Type of Findings	Individual Reasoning-blocks	Group Interactions
Unexpected Findings	21	67
(explanatory reasoning)	(8)	n/a
(erroneous reasoning)	(13)	n/a
Expected Findings	-	-
Exploratory Findings	3	21
Total	24	88

[a]Reasoning-blocks of the substantive experimenter
[b]Group Interactions (simple talks, debates, etc.) about the reasoning-blocks of the doctoral student K

Table 7 Distributed reasoning with respect to the hypothetical suggestions

Intervention	Total	Agreed		Disagreed	
		Accepted	Expanded	Replaced	Discarded
Intervention	7	1	3	3	-
Non intervention	1	1	-	-	-

weaknesses of the studies performed by individuals alone. With the result above where the most original reasoning suggested by the substantive experimenter were expanded or modified through group discussion, the merits of distributed reasoning is verified. This indicates that it is hard for an individual to suggest alternative hypotheses by overturning his first idea himself, but the distributed reasoning may overcome such difficulties.

The number of scientists who were involved in the distributed reasoning is another issue, which investigates how many scientists have shared the same reasoning. The percentage of two things is examined for this: (a) percentage of inferential group interactions except for the simple talks (Group interaction is all kinds of interactions including simple talks, so distributed reasoning is one of such interactions) (b) percentage of agreement of opinions between more than two scientists. By doing so, it is possible to verify if the distributed reasoning is a frequent phenomenon and confirm the process of knowledge diffusion among the members.

As shown in Table 8, when it comes to percentage of the distributed reasoning, 40 in 67 group interactions (Unexpected findings) and 15 in 21 group interactions (Exploratory findings) were identified as distributed reasoning, which is almost 60 and 76% respectively. The result shows that scientists develop reasoning about new fact that they discovered very intensively, which implies that the interactive lab meetings function as a forum for intensive thinking, not a simple communication.

The proportion of agreement among the members was 23 in 40 distributed reasoning (Unexpected findings) and 10 in 15 distributed reasoning (Exploratory findings), which is almost 58% and 67% respectively. The result shows that scientists often reached to an agreement while discussing together. In other words, distributed reasoning help diffuse knowledge in most of the cases and becomes a stepping-stone to new knowledge.

Conclusions and implications

In the study, we verified whether the three sources of scientific creativity suggested by Dunbar can be applied in the case of KRICT. Our results found that (a) analogical

Table 8 Percentage of distributed reasoning in group interactions

	Unexpected findings	Exploratory findings
Group Interactions (GI)	67	21
Distributed Reasoning (DR)	40	15
(Agreement of more than two scientists)	(23)	(10)
Proportion of Distributed Reasoning (=DR/GI x 100)	59.7%	76.2%
Proportion of Agreement in DR (=Agreement/DR x 100)	57.5%	66.7%
Total Proportion of Agreement (=Agreement/GI x 100)	34.3%	47.6%

reasoning is very frequent in KRICT too (b) scientists pay close attention to the unexpected findings (c) scientists settle differences through vigorous distributed reasoning.

However, we found that KRICT case shows two different modalities of scientific creativity unlike Dunbar. First, KRICT researchers treated the unexpected research outcomes as a sort of experimental mistakes like measurement errors, but the scholars in US universities thought them as something new or something need to be explained in different way. Secondly, a majority of distributed reasoning belonged to the agreement in KRICT case, but scientists were much more critical to each other during group discussions in US cases.

Further research is needed to know whether such discrepancies result from distinctive characteristic of universities (academic freedom guaranteed) and public research institutes (pressure of goals-achievement on time) and how the difference would affect the research productivity.

Organizational knowledge-creation of nonaka

Nonaka (1994) studied how knowledge is created and spread throughout internal employee in the level of terminal units, departments and a whole corporation respectively. He said that new knowledge necessarily begins from an individual but organizations play a critical role in articulating and amplifying that knowledge. Organizations act as a medium for making the knowledge available resources by developing it.

He has divided the stage of knowledge creation and conversion into 4 phases: (a) Socialization: Individuals create an original idea by getting certain stimulus from the external environment (b) Externalization: Vague tacit knowledge of socialization phase is developed to an explicit knowledge with clear conception (c) Combination: A variety of explicit knowledge combine together in this phase and often converted into new applications (d) Internalization: The new knowledge spread throughout the organization and the employees learn and internalize them[3] (Nonaka et al., 2000; Nonaka & von Krogh 2009).

The Spiral model of Knowledge creation and conversion has relevance with the results of our study in two respects. Firstly, Nonaka said the 'Externalization' process is often driven by metaphorical analogies, which is one of the three important sources for scientific creativity in KRICT case. Ideas from analogous fields play a key role in making new hypotheses and concepts as long as the analogical distance is not too far, which suggests that such analogical reasoning is important to convert tacit knowledge into explicit knowledge.

For example, the researchers in our observation professor B of the University S specialized in bulk-scale chemical particles and the lab members in KRICT specialized in nanoparticles such as MOFs. The professor B used to explain the result of experiments with different knowledge background. He was often able to cast a new light on some problems by drawing an analogy from bulk-scale chemistry when making hypotheses and analyzing the result. Part of the discussion which shows such an analogical reasoning is presented below.

Figure 1 clearly shows the importance of close analogy in developing an idea with different point of view. At the same time, the analogical reasoning should be moderately distant. It would be much more synergetic when experts of adjoining field put heads together rather than people from remotely separate fields.

Professor B: Well, I don′t know for sure about the MOFs… Actually, that′s more often the case on surface. In the case of single crystalline solid, the distance between the first layer and the second layer is dependent on what is adsorbed on the surface. The distance may increase or decrease. The distance may vary with changing of bonding one another and electronic environment around them. It is not necessary for somethings to be situated in a porous.

Researcher D: Oh… even if they are situated outside?

Professor B: Yes. When platinum is arrayed like this… (*Analogical explanation with hand movements*) When the sequence of the first and the second layer is like this… If oxygens adhere to the surface, the distance between two layers may be gradually changed.

Researcher A: Even with XRD (*X-ray Powder Diffraction*)?

Professor B: Yes. Of course in bulk-scale, it doesn't change in deeper place. But, on surface, that′s very often.

Fig. 1 An example of lab meeting with analogical reasoning

Secondly, it is said that meetings and telephone conversations act as an important medium in 'Combination' process, and this is concerned with the third factor (distributed reasoning) of scientific creativity in our study. The fact that scientists also create new ideas and alternatives through group interactions in laboratory meetings suggests the possibility of applying the SECI model to knowledge creation process of scientists, not to mention the corporate organizations.

As shown in Fig. 2, the KRICT laboratory was playing a role as medium for connecting lab members and provided a place for share opinions, which corresponds to the *organization* in Nonaka's model (*Organizations act as a medium for making the knowledge available resources by developing it).* The lab members correspond to the *individual* as new knowledge comes out from separate human and an organization amplify the knowledge.

In this sense, this study of scientific creativity has a deep relation with the principle of open innovation as well. Open innovation is defined as 'the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation, respectively' (Chesbrough et al. 2006). The result of this study on the specific behavioral pattern of scientists with respect to the analogical and distributed reasoning can be interpreted as the open innovation by letting external knowledge flow into the inner group.

Supply-side perspective of innovation

The study of creativity basically stands on the supply-side perspective, because creative research generally contrasts with public research programs in most public research institutes. The recent missions of the public research institutes in the world are generally classified into publicness, connectivity and excellence, and the excellence is drastically different from the publicness based on the demand-side perspective (Ko, 2012).

Nemet (2009) introduced two critical arguments toward such supply-side perspective as follows, with summarization on the history of theoretical debates between

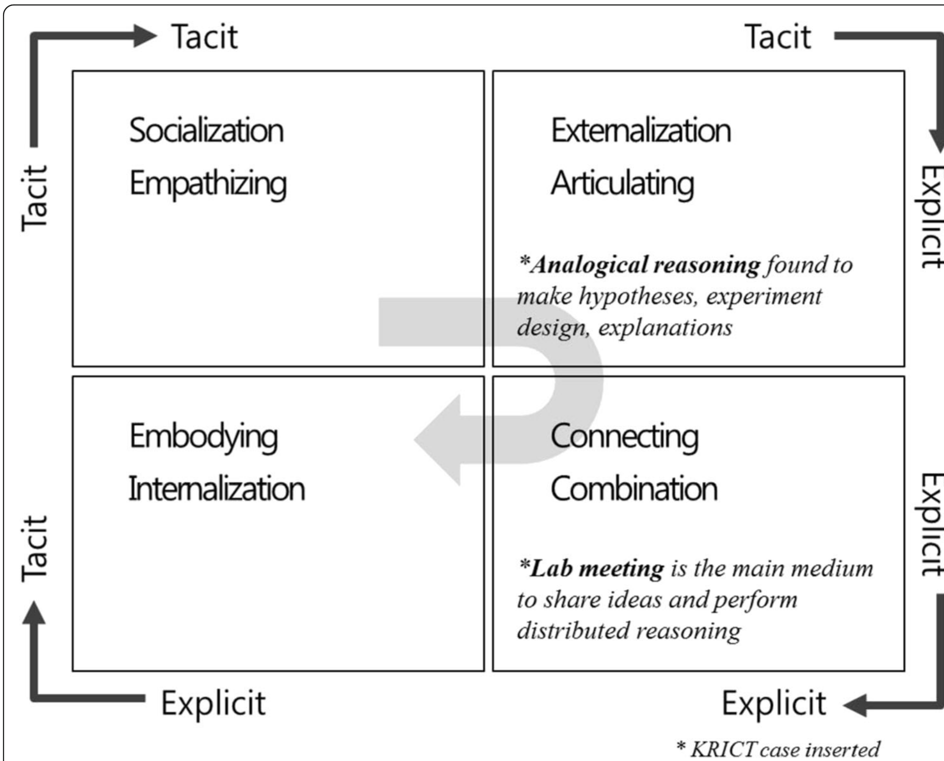

Fig. 2 Nonaka's SECI process with KRICT case inserted

technology push model and demand pull model in innovation study. First, supply-side theories ignore change in economic conditions such as prices, etc. that may affect the rate of return. Secondly, supply-side theories describe innovation process as a unidirectional progression and not compatible with the later Innovation System theories emphasizing feedback, interaction and network. Kline and Rosenberg, Freeman (1994), Freeman and Louca (2001) are representative of that non-linear innovation study, which have developed to the innovation system theory today. However, the network between scientists with different academic backgrounds was also important for creativity as we verified in the distributed reasoning. Given the importance of such various backgrounds, the second criticism is doubtful that the technology push model is not compatible with innovation system theory.

Although Kodama elaborated the demand articulation from the open-innovation perspective as market driven and market driving (Kodama & Shibata, 2015), various studies of creativity also has a significant implication that elaborates the detailed description on innovation from the fundamentally supply-side perspective. Those may improve balance between supply-side and demand-side perspective in innovation study by suggesting different viewpoint to such a trend of demand-side R&D activities.

Endnotes

[1]Wet lab is mostly the classical laboratories in chemistry, biology, genetics and etc. field. On the other hand, the laboratories for the theory study and computer-based study are called Dry Lab.

[2]An analogical reasoning consists of target and base. The target is a problem which needs to be solved, or a concept which needs to be explained clearly, while the base is a certain knowledge drawing from the related filed to reinterpret and explain the target, to help understand the target more clearly and from different point of view. In other words, the distance of analogy shows how far the target is located from the base conceptually.

[3]SECI model, Socialization – Externalization – Combination – Internalization.

Authors' contributions

J was mainly responsible for executing the study such as data collection and analysis. He selected an interviewed laboratory and conducted long-term participated observation of its lab meetings, and analyzed the qualitative data obtained in that process. He also summarized the rationale for a relevance of this study to innovational system theory and the theory of Nonaka. K was mainly responsible for making the research plan. He offered counsel on formulation of the research purpose and direction. In particular, he advised on selecting the appropriate laboratory for participated observation based on long experience as a policy expert in Korea Research Institute of Chemical Technology. He also offered ideas about the theoretical implications. Both authors read and approved the final manuscript.

Competing interests

I confirm that I have read SpringerOpen's guidance on competing interests and that none of the authors have any competing interests.

Other sections

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