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How work positions affect the research activity and information behaviour of laboratory scientists in the research lifecycle: applying activity theory

Nahyun Kwon

Introduction. *This study was conducted to investigate the characteristics of research and information activities of laboratory scientists in different work positions throughout a research lifecycle. Activity theory was applied as the conceptual and analytical framework.*
Method. *Taking a qualitative research approach, in-depth interviews and field observations with twenty-four bio- and nano-scientists were conducted at science laboratories in South Korea. A micro-moment time-line interview and critical incident technique guided the interviews.*
Analysis. *Transcribed interview scripts, field notes, and video-recorded images were analysed using the frameworks of activity theory and the research lifecycle.*
Results. *Laboratory scientists were largely divided into principal investigators and junior scientists supporting them. Each group used different information sources for different purposes throughout the research lifecycle. The study also revealed the socio-cultural norms and rules affecting the division of labour. All of this contextual information shaped the information behaviour of the scientists in different positions.*
Conclusion. *Work position was revealed as a critical factor characterizing scientists' research and information activities. The study constructed a model explaining the division of labour among laboratory scientists in the research lifecycle. Socio-cultural norms should be taken into account when system designers and policymakers design new scientific research support systems.*

Introduction

Scientists have been a popular subject group for information researchers because of the nature of their profession that actively uses, exchanges, manages, and produces various information sources (Case, 2009; Ellis and Haugan, 1997; Haines, Light, O'Malley and Delwiche, 2010; Niu and Hemminger, 2012; Palmer, 1991; Roos, 2012; Sahu and Singh, 2013). Scientists are not considered a homogenous group because their information behaviour varies by subject field. Understanding this caveat, researchers have limited their study population to specific subject areas (e.g., physics, astronomy, medicine) or by research type (e.g., pure, applied, or industrial research) (Case, 2012; Ellis and Haugan, 1997; Palmer, 1991; Talia, Vakkari, Fry and Wouters, 2007; Tenopir and King, 2002; Tenopir, King and Bush, 2004). Although some of these studies have alluded to information behaviour unique to particular work positions (Ellis and Haugan, 1997; Palmer, 1991; Sahu and Singh, 2013; Sapa, Krakowska and Janiak, 2014), few have examined it exclusively.

Differences in information behaviour caused by work position can be extrapolated from the way that laboratory scientists work. Unlike most scholars in the humanities and social sciences, teams of scientists work on projects in a laboratory (hereafter, lab) equipped with expensive research apparatuses. As the smallest unit of science communities, science labs are reported to have their own culture, work procedures, norms, and rules by which its members abide (Latour and Woolgar, 1986). Subject expertise and work position determine the division of labour in the lab, and each member is assigned his or her tasks accordingly. As the junior-level scientists play different roles from their senior counterparts, their information seeking and uses would also be different. However, the existing literature falls short of exploring how work positions specifically affect laboratory scientists' information behaviour in their research processes.

The purpose of this study is to investigate the characteristics of research and information activities of laboratory scientists unique to their work positions in the lifecycle of a research project. In particular, Engeström's (1999) activity theory was adopted as a theoretical framework data collection method, and analytical tool. Activity theory is claimed to be effective in investigating the influence of contexts regarding information behaviour and use of technology; moreover, its research findings could help remedy contradictions in the real world (Allen, Karanasios and Slavova, 2011). While many information researchers have contended its applicability and usefulness (Allen *et al.*, 2011; Spasser, 1999; Wilson, 2006, 2008), few have applied activity theory to identify distinct characteristics of laboratory scientists' information activities when those scientists are working in different work positions. Hence, the following two research questions were investigated in this study:

> *RQ 1: In each phase of the research life cycle, what are the key research activities of laboratory scientists in different work positions?*
> *RQ 2: In each research phase, what are the key characteristics of the information behaviour of laboratory scientists in different work positions?*

Data were collected through qualitative research methods. In-depth interviews with twenty-four bio- and nano-scientists working in different positions were carried out at science laboratories in South Korea. Carrying out the research at the participants' workplace, this researcher was able to make observations of laboratory environments, research activities, and interactions and group dynamic among the lab members. The findings of this study could offer rich information about unique research and information activities of laboratory scientists working in different positions, which could help develop customized research support systems to meet the information needs of scientists in various work positions. Furthermore, the results could inform the usefulness of activity theory as a relevant analytical framework to uncover the characteristics of scientists' information behaviour in various work positions.

Literature review

For the purpose of this study, the following three areas of literature were reviewed: (a) the scientific research lifecycle; (b) scientists' information behaviour; and (c) activity theory and information behaviour.

Scientific research lifecycle

Networked digital information technology has been changing information behaviour in human activities, and scholarly communications in academic research are no exception. In the field of science and technology, there have been active experiments supporting scientific research with an understanding of the scientific research lifecycle. Humphrey (2006) presented the knowledge transfer cycle model that demonstrates the types of information sources scientists use, create, and transfer at each stage of the research process. The model consists of a six-stage cycle: conceptualising, initialising, analysing, generating initial results, formalising, and popularising. By visualising each research stage, this lifecycle model could help detect and fill the gaps between research stages.

The Research Information Centre project is one of the virtual research-supporting systems designed against the backdrop of research lifecycles (Barga, Andrews and Parastatidis, 2007). Here, the lifecycle consists of four stages: discovering idea(s); obtaining funds; experimenting, collaborating, and analysing; and disseminating results. This lifecycle model has been used to design an integrated virtual research platform. As an information support system for scientists, the platform can help scientists at each research stage access various information and research tools, including e-mail, RSS feeds, information-sharing programs, bibliographic databases, and other research-supporting software. Similarly to the Research Information Centre, Britain's Joint Information Systems Committee developed the Virtual Research Environment to help researchers utilize various research tools, communicate with colleagues, and develop information communication technology infrastructures (Barga *et al.*, 2007).

Kwon, Lee and Chung (2012) also examined the lifecycle of science research and development projects as a way of understanding South Korean laboratory scientists' information needs and source uses. The lifecycle identified from this South Korean study was a cyclic five-stage process: generating ideas, securing funding, experiments and analysis, generating research products, and evaluation (Figure 1). This lifecycle generally confirms the earlier endeavours by revealing a similar course of stages that are involved in scientific research activities.

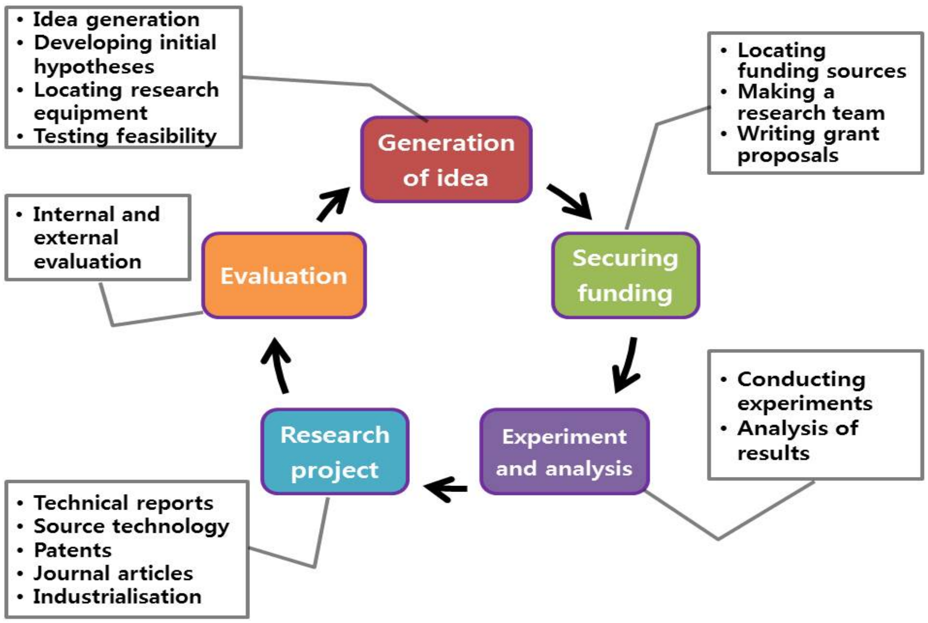

Figure 1: Scientific research lifecycle (Kwon, Lee and Chung, 2012)

Instead of dealing with the general research lifecycles introduced above, some systems have dealt with a particular research stage. Focusing on the experimental stage, myExperiment, for example, was developed for young scientists to share, re-use, and repurpose experimental protocols and workflows in such fields as bioscience and chemistry. Designed to be used on Facebook, the site helps young scientists share research tips and tactics. Research libraries have invested in the development of research-supporting systems based on the research lifecycle model (Association of Research Libraries, 2007). Such efforts are linked to the greater endeavours of information behaviour research, which seeks better understanding of the information behaviour of professional occupation groups, such as laboratory scientists.

Information behaviour of scientists

Information behaviour research has investigated a wide range of scientists' activities, including how people access, use, analyse, and create information. It examines information behaviour in a context where information needs and uses occur so as to learn how people use information sources to solve problems (Dervin, 1992). The lifecycle of scientific research reflects scientists' workflow, which can be an effective way of understanding the context of scientific research. Ellis and Haugan (1997) investigated scientists' and engineers' information seeking by taking a research lifecycle approach. They revealed that different kinds of information channels and sources were selected and used in different research phases.

A few researchers have reported the importance of work positions and roles in understanding information behaviour. For example, Palmer (1991) conducted semi-structured in-depth interviews to explore the factors affecting the information behaviour of agricultural scientists. The key factors determining their information seeking were discipline, work roles, and time spent on the subject field and organization. Niu and Hemminger (2012) analysed a series of structured surveys collected from 2,063 academic scientists in natural science, engineering, and medical science at five US research universities. The most important determinant of information behaviour was academic position, which reflects the years of experience and the complexity of the tasks that scientists undertake.

Three recent studies are noteworthy as they explicitly compared researchers in different work positions. First, Sapa *et al.* (2014) surveyed twenty-one professional mathematicians and 153 students in Poland to compare the two groups' information seeking behaviour on the Internet. While there were few differences between the two groups, the differences were mostly visible in the usage of Web 2.0 sites, which were far more popular among the students. In another study, Sahu and Singh (2013) examined the information behaviour of 400 astronomy and astrophysics scientists in India. While the authors suggested different information seeking behaviour by position, details about these differences were not reported in the study. Finally, Isah and Bystr?m (2016) looked into different information practices of a team of senior and junior physicians in an unspecified African university hospital to study workplace learning and the physicians' everyday information practices in patient care. The authors noted that the adoption of hierarchical social positions reflected in their methods of accessing information might be due in part to the strong apprenticeship system in medicine and to some cultural traits of that society. Nonetheless, a review of literature on scientists' information behaviour reveals that work position and roles have not been examined exclusively but rather sporadically in the empirical studies.

Activity theory and information behaviour

Originally postulated by Vygotsky in the cultural-historical school of Russian psychology, activity theory was shaped in its basic theoretical structure by Leont'ev, who also introduced the concept of activity. Vygotsky viewed human activity as social in nature, and paid attention to the coevolution of individuals and the world around them (Allen *et al.*, 2011). This perspective is rooted in his sociocultural theory of learning, contending that learning takes place not only through the influence of individual actors but also through cultural beliefs and attitudes (Vygotsky, 1978). Spasser (1999, p. 1136) claimed activity theory '*is a philosophical framework for studying different forms of praxis as developmental processes, with both individual and social levels interlinked*'. This suggests that the theory could provide a useful framework for studying the information behaviour of a group of individual laboratory scientists participating in a research project as a collective activity.

Activity theory was further elaborated by Engeström (1987), who proposed a conceptual diagram of six nodes: subject, objects, tools, community, division of labour, and rules and norms (Figure 2). It illustrates a subject (or actor) of an activity, driven by motivation, who undertakes an activity to obtain a certain object. This process is mediated by tools that take both physical (e.g., books, equipment, human beings) and abstract form (e.g., ideas, language, memory, skills). The actor's activity takes place in a community where its members play their roles through the division of labour, and the rules and norms are shared among the members when performing the activity.

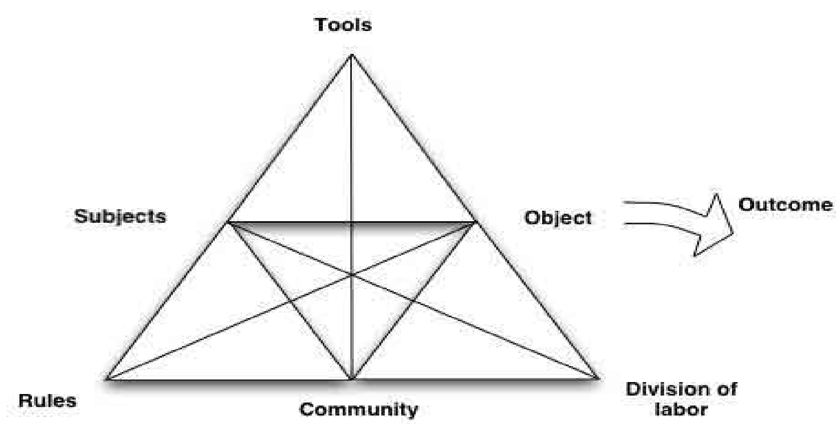

Figure 2: Engeström's (1987) activity theory

Recognizing the value of this theory in studying human information behaviour in context, a handful of researchers have advocated its application to information behaviour research (Allen *et al.*, 2011; Spasser, 1999; Wilson, 2006, 2008). Along with the seemingly intuitive six nodes that can effectively explain the activity in context, researchers have also been attracted to the concept of contradiction, as they see it as a place to identify problems in an activity system and to enhance current practices through proper interventions of policy and practice (Allen *et al.*, 2011).

Among a handful of studies that have applied activity theory, Roos

(2012) investigated the information behaviour of Finnish scientists in molecular medicine by conducting semi-structured interviews with senior researchers and graduate students. This study demonstrates the theoretical usefulness of activity theory by contextualizing information activities in scientists' work process. It is noteworthy that Roos suggested both differing information needs and behaviour between senior researchers and graduate students, possibly resulting from differing motives and roles between the two groups. Isah and Byström (2016) also recognized the value of the theory in examining the sequential process of information seeking in context in their aforementioned African university hospital study, yet they did not fully explore the nodes in the theoretical model.

In summary, the above review of related literature suggests the usefulness of activity theory in examining the following: an individual laboratory scientist's research activities in context, the process of research activities and the dynamics within it, and the research and information seeking activities that scientists employ in different work positions. In particular, the concept of division of labour, as specified by activity theory, is expected to help uncover the unique characteristics of scientists based on their work positions.

Research methods

Research design and theoretical frameworks

The purpose of this study is to investigate how scientists' information behaviour differs in the laboratory research process because of their work positions. Taking a qualitative research approach, the study used in-depth interviews and field observations as data collection methods. Interviews were conducted at the participants'workplaces. This allowed the researcher to observe the research activities, research environment, and interactions among the laboratory members. In particular, a critical incident technique was employed, where each participant was asked to recall either the most important or the most recently completed research project in which s/he had participated, and to describe the entire process from the beginning to end. Each participant was interviewed twice. The first interview collected participants' background information and the overall research process of a selected project. Detailed information of the selected project was collected in the second interview conducted a week later by employing Dervin's (1992) micro-moment time-line interview technique.

As a conceptual framework to guide the interviews and data analysis, the study developed a conceptual model (Figure 3) by incorporating two theoretical frameworks, namely (1) Engeström's (1999) activity theory and (2) Dervin's (1992) sense-making theory.

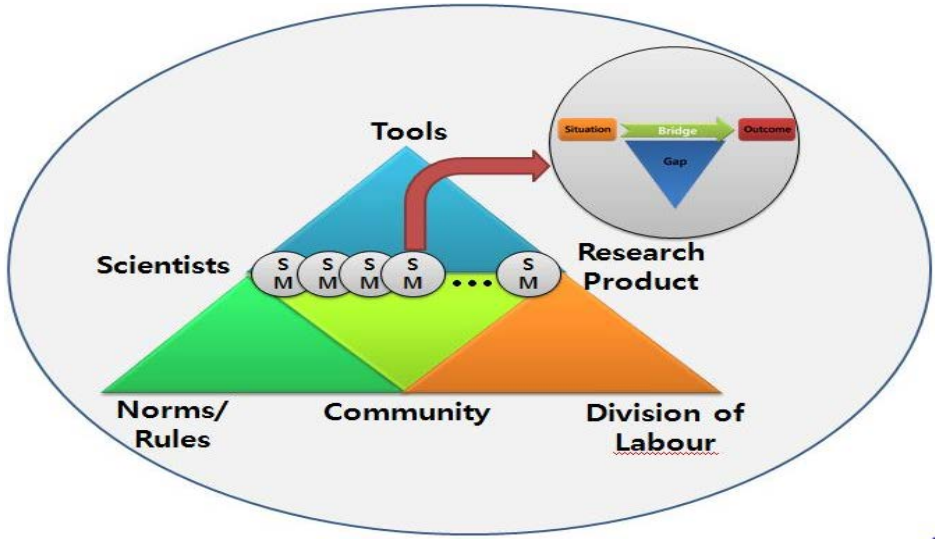

Figure 3: Conceptual framework of the data collection and analysis (SM: sense-making)

First, as the central theoretical framework, the six nodes of Engeström's activity theory were adopted to understand the research activities and information behaviour of laboratory scientists working in different positions. Second, Dervin's sense-making theory was adopted to guide in-depth interviews. Specifically, its triangular notion of situation-gap-help was used along with the micro-moment timeline interview technique. It stipulates the process of how a particular actor, situated in a specific space-temporal context, behaves when s/he encounters a problem, and how s/he bridges the gap between the problem situation and the goal by using various strategies and methods. Noting the fact that research activity is a constant process of problem solving, the theory is an intuitively useful framework to identify not only the problem, actions, and operations to solve the problem, but also the tools used to solve problems. Table 1 presents the interview guide that shows the kinds of information collected from the interviews along with related theoretical concepts.

	Categories	Sub-categories	Specific information collected	Theoretical concept
1st round interview	Participant background and research context	Researcher	academic degree, major, age, gender, affiliations, work positions, roles, tasks, research interests	Activity theory-Subject Activity theory-Division of labour
		Community	laboratory, professional society, affiliated institutions	Activity theory-community; Activity theory-rules Activity theory-

				division of labour
	Overall research process	Phases of research livecycle	phases of research and development project lifecycles, outcomes in each phase	Activity theory-object
One-week intermission: extracting a research lifecycle of a particular project based on the first round interview of each participant				
2nd round interview	Research activities and information seeking at each of five research phases (repeated)	Situations	problem situation	Sense-making-situation
		Gaps	problems, contexts	Sense-making-gap
		Bridges and tools	tools used to solve problems, information tools and solutions, colleagues, social media, library, laboratory notes, etc.	Sense-making-bridges Activity theory-tools Activity theory-division of labour
		Outcome	success or failure of each lifecycle stage, degree of importance, difficulty, satisfaction	Activity theory-object Sense-making-outcomes

Table 1: In-depth interview guides with related theories

Research participants and sampling

The subject areas examined in this study were limited to the bio- and nano-science and engineering fields. These are the subject fields where laboratory scientists from various backgrounds collaborate actively, and the nature of the research ranges from basic to applied. A total of 24 scientists from 16 science laboratories were recruited using snowball sampling. They were affiliated with five universities located in five different cities in South Korea and with the largest bio-science and engineering institution in the country. The participants included 16 bio-scientists (67%) and 8 nano-scientists (33%). Regarding work position, 13 participants were principal investigators (principal investigators-54%) who have their own labs, three post-doctoral researchers (13%) and 8 graduate research assistants (33%). The latter two groups are junior scientists hired by their principal investigators. Regarding age breakdown, six participants were in their 20s (25%), seven in their 30s (29%), eight in their 40s (33%) and three in their 50s (13%). Detailed information for each participant is listed in Appendix 1.

Data analysis and coding framework

In-depth interviews with twenty-four research participants produced a total of 57 hours and 30 minutes of interviews with an average of 2 hours and 24 minutes for each participant. Each interview was entirely tape-recorded and then fully transcribed. The transcribed interviews, field notes, video recording, and photos were used for the data analysis.

Note that one of the motivations of the study was to test the applicability of activity theory to the proposed research purposes. Thus, instead of applying a complete open coding technique, a rough coding scheme was developed at the outset based on the conceptual framework of this study (Figure 3) and the scientific research lifecycle (Figure 1). That is, the coders attempted to identify the elements in terms of the six nodes of activity theory and the five nodes of the research lifecycle. Two coders analysed the contents of each interview transcript against the categories and nodes in the coding scheme using Nvivo 9, a qualitative data analysis software program. Through this process, coders were able to establish a common understanding of the categories and nodes in the coding scheme, which facilitated the inter-coder reliability of the data analysis. The initial coding framework was streamlined into the final coding framework (Table 2). Additional details of the coding procedure are delineated in Chung, Kwon and Lee (2016). The initial results of the data analysis were reviewed and verified first by three research participants individually and then collectively in a focus-group interview format.

The evaluation of qualitative research is assessed by the four criteria that ensure trustworthiness of a research study, namely credibility, transferability, dependability, and conformability (Lincoln and Guba, 1985). The researcher attempted to establish credibility (i.e., confidence in the truth of the findings) by having three participants member-check the research findings. Transferability, a type of external validity, was pursued by making thick descriptions of the research, in which the phenomena observed in the field were described in sufficient detail so that the conclusions drawn could be transferable to other contexts. Dependability was addressed through methodological triangulation by applying multiple data collection methods. Conformability, a degree of neutrality, entails full revelations of the data so as to assess whether the data confirm the findings of the study. Conformability was attempted through the use of triangulation of multiple data collection techniques as well as thorough record keeping of interview transcripts, field notes, memos, and photographs for potential inspection (Denzin and Lincoln, 1994, p. 513).

		Categories	Examples of coding nodes
Research lifecycle	1	Idea generation	idea generation, developing initial hypotheses, locating research equipment, conducting feasibility tests
	2	Securing funding	locating funding sources, making a research team, writing research grant proposals to secure funding
	3	Experiment and/analysis	conducting experiments, analysis of results
	4	Research product	technical reports, source technology, patents, scientific journal articles, industrialization
	5	Evaluation	internal evaluation, external evaluation
Activity theory	1	Actors	academic major, work position, highest academic degree achieved, age
	2	Objects	journal articles, patents, industrialization, impact obtaining grants
	3	Tools	information sources (literature, academic societies, personal sources, social media, co-workers, preferred sources), equipment or apparatus (desired tools, software), collaborations (information sharing, communication tools)
	4	Community	affiliated institutions (size, subject area, academic or research institutions), affiliated laboratory (size, subject area), domestic and international academic societies, social capital (nature, types), collaboration partner selection
	5	Rules and norms	policies, lab culture, generation gap, collaboration practices, information sharing, communication methods within lab, communication methods between labs
	6	Division of labour or roles	division of labour within lab, division of labour between labs, roles, formation of collaboration, motivations for collaboration

Table 2: Coding scheme for the qualitative data analysis

Results

Division of labour in the five-phase research lifecycle

In-depth interviews with twenty-four scientists revealed that positions in the science community are largely divided into two groups: the principal investigator level and the junior scientists supporting the principal. Positions are determined by subject expertise, educational attainment, and research productivity. The division of labour identified in this study was largely compatible with Latour and Woolgar (1986), who separated the laboratory scientists into two groups: doctors who read and write in offices versus technicians who spend most of their time handling equipment in the lab.

The principal investigator generally refers to the lead researcher for a particular project, which often means the head of the laboratory or research group leader (Casati and Genet, 2014). This level includes senior researchers and senior research fellows in science institutions and professors in academic institutions. They normally have their own science labs and are responsible for acquiring grants.

The junior scientists work under the direction of the principal investigator. Because scientists' career paths move up to the principala level as they build their credentials (Latour and Woolgar, 1986; Sahu and Singh, 2013), junior scientists tend to be younger, with an age range of between 25 and 35 in this study. Junior scientists include post-doctoral fellows who have earned a doctoral degree, and those without it (e.g., M.A. and Ph.D. graduate assistants and laboratory technicians). Post-doctoral researchers join a principal investigator's lab when their subject specialties match the lab's research area, carrying out research projects by closely assisting the principal investigator. They then tend to move toward the principal investigator position as they build their research careers, and may play middle-management roles in bigger research labs. Graduate research assistants are in a Ph.D. or M.A. degree programme working as assistants affiliated with either an academic or research institution. They work for the principal investigator, carrying out experiments closely associated with their thesis writing. In general, they are assigned to a research lab when their research area is roughly decided. Their dissertation or thesis topics are normally developed from their coursework, which is also aligned with the lab's current research interests.

Lastly, there are laboratory technicians, working as either part-time or full-time employees. Their educational background varies from upper-level undergraduate students to those with a master's degree. Although there are variations based on their qualifications, their role is largely to assist other scientists in the lab with more practical aspects of research: conducting tests and experiments, gathering, interpreting, and recording research data, operating and maintaining computer and lab equipment, analysing specific substances, and ordering inventory and shipping samples. While technicians play important roles as reported in Latour and Woolgar, they were excluded from the analysis partly because their roles are played mostly by the graduate assistants in South Korea, and partly because they work as assistants rather than researchers pursuing their own scientific discoveries.

The findings below report how scientists in different positions play their roles (i.e., division of labour) in each of the five phases of the scientific research lifecycle: (1) idea generation, (2) securing funding, (3) experiments and data analysis, (4) generating research products, and (5) evaluation (Figure 1).

Idea generation: phase 1

The first phase consists of two parts: (1) idea generation and developing the initial hypotheses, and (2) locating research equipment and conducting feasibility tests. A new research project generally begins when scientists, typically principal investigators, are motivated to explore a new research idea generated by their previous research:

> *First, I published papers from the New Researcher Grant of the National Research Foundation, and those papers enabled me to get the next funding. As I was accumulating more data and outcomes over the years, new ideas emerged naturally. And....you keep on going, repeating this cycle. (Nano-5, PI)*

Although there are variations in principal investigator's leadership styles, they often offer rough ideas on a large scale, which allows the lab staff to develop a plan to initiate a specific research project.

> *When you assign tasks to students, the first thing to do is have them find a reason for the study. Then you tell them,'Write up a roadmap to get there.' The roadmap means to check if someone has published a paper with that idea or has a patent for it....You get to work only when you're absolutely sure that no one has been there before. (Nano-2, PI)*

Post-doctoral fellows usually work on a project assigned by the principal investigator, whom they help to generate and develop research ideas, and sometimes take the primary role on a research sub-project (Bio-10). Because of their highly-developed expertise, they are able to conduct advanced research. In the graduate students' cases (Nano-3), too, the research topic is generally assigned by the principal investigator, and students usually work on multiple projects simultaneously:

> *I joined the project team after it became our lab's main focus. The field of thermoelectricity isn't a single-faceted theme, so we've been branching out the theme by assigning multiple people to different parts. (Nano-3, Graduate student)*

As seen above, junior researchers do not agonize much over idea generation. Following the order of the principal investigators, junior scientists actively survey the literature to see what has already been done. Ellis and Haugan (1997, p. 395) called it *surveying*, which is one of the eight major information seeking patterns,(surveying, chaining, monitoring, browsing, distinguishing, filtering, extracting, and ending). Interviewees heavily depend on Google keyword searches. They also check the Websites of the core journals in their field. They usually bypass library Websites and go directly to the journal homepages. Comprehensive databases are also used as a key information source, and differ by subject. Such sources include *PubMed* for bio-scientists and *SciFinder* for nano-scientists. Using these sources, junior scientists gather previous literature and the latest trends in their area. Defined roles are expected of researchers in the different ranks, and a distinctive division of labour appeared to be the norm in science labs.

When asked about the difficulties of idea generation, interviewees gave answers that varied according to experience and rank. One principal investigator (Nano-6) said that there are ideas generated by seeing the trees, whereas there are *really good* ideas generated by seeing the forest itself, which can lead to meaningful research. The latter is rare and can only be expected from established scholars. This can explain why even the highly experienced lab *supertechnicians* refrain from seeking a Ph.D., thinking that they lack such ability to play in the major league (Latour and Woolgar, 1986, p. 218). To generate such macroscopic ideas, principal investigators constantly scan their environment; they monitor the latest trends in their fields by actively attending international conferences:

> *I often get very useful information as I attend international conferences. They sometimes summarize the most significant research findings in the past 10 years. You get most valuable information there. (Nano-1, PI)*

This finding confirms Ellis and Haugan's (1997, p. 396) contention that scientists attend international conferences and other international forums for *monitoring*. *Chaining* was another strategy that a highly established principal investigator (Nano-7) was actively utilizing to formulate a new research question:

> *One important thing we do is to examine the papers that have cited our papers.... In my lab, we got 500-600 citations a year. We have a new article citing our work almost every day... Reading those papers helps us know our next research to branch out, without even doing any experiments or investment... Reading them keeps us very busy, but I am very serious about doing it to get new ideas. (Nano-7, PI)*

Once scientists identify an idea worth testing, they move to the next stage to form the idea. They ask junior scientists to check the availability of the various research tools to test the idea: '*The first thing you do is to determine if the task is feasible, and if it is, then we* *locate the systems that can make it possible*' (Bio-15, PI).

Research tools in this phase include lab equipment, apparatus, and/or instruments, testing materials, chemical reagents, or fellow scientists owning needed equipment or techniques. Feasibility tests involve reviewing related literatures and executing mini-experiments. The division of labour, or assignment of roles, is established as a norm in the lab community throughout the first phase. The tests are usually conducted by junior members, and the results are reported to principal investigators. This process enables the principal investigators to develop more specific research hypotheses. All of the lab members also check the accessibility of lab equipment by consulting literature, company Websites or their catalogues, and consulting colleagues in and out of their lab, including online communities. When the junior staff fail to access the required equipment for tests, principal investigators use their personal networks to find persons to borrow from and, sometimes, to invite the owner as a research partner. This finding supports Ellis and Haugan's (1997) contention that '*collaboration and dialogue with scientists and other scholars... are considered to be of great importance and to be the most effective way to get information*' (p. 397). Scientists'personal networks are an important tool for idea exchange and collaborator scouting. Directory databases are less useful than personal networks when selecting research collaborators. This is because the quality and trustworthiness of the collaborator are usually proven by first-hand experience or reputation in their community.

Securing funding: phase 2

The second phase of the research lifecycle includes three major activities: (1) locating funding sources; (2) making a research team; and (3) writing a grant proposal. Different from the humanities and social sciences, funding is critical to the laboratory research. Without funding for research equipment and the salaries of junior researchers, a project is virtually impossible to conduct. Latour and Woolgar (1986, p. 217) put it as 'capital and labour intensive'. The major activities in phase 2 are carried out by principal investigators: those with stronger personal networks and more research output are likely to have access to greater funding opportunities. Because submitted proposals are not always successfully funded, principal investigators work under great stress especially when budgets are tight. As one principal investigator said,

> *I'm running on a very tight budget. It involves a lot of pressure. You'd have to hire around 5-6 students to get the research going, and for that, you'd need at least 100-200 million won. Everything costs money. Buying the tiniest amount?five grams?of some material costs 500,000 to 1,000,000 Korean won (Nano-5, PI)*

Junior staff generally did not know much about funding sources, but they understood the principal investigator's funding stress because they were aware of the consequences of funding failures. They would suffer from insufficient supplies, discontinuance of their current experiment, and in the worst-case scenario, termination of their employment.

When writing grant proposals, principal investigators formalize the project team formation. Within the lab, project participants are chosen based on the principal investigator's assessment of the lab members' subject interests, competencies, and other circumstances unique to the lab. Principal investigators identify possible collaborators outside the lab through informal, private communication channels (i.e., e-mail, telephone, physical visitation, or casual chats at conferences) rather than formal channels, such as directories.

In the grant writing process, roles are distinctly divided. Normally, principal investigators play the key role in writing, while junior staff members assist the principal investigators with preparation. Most principal investigators have a good working knowledge of grant sources, and they write grant proposals based on their understanding of how their topics suit the grant programme. Experienced principal investigators can write proposals rather strategically and technically because they understand the trends in and perspectives on the subject area:

> *In the beginning of my career, it literally took me one month of constant agony to write a single page.... Now it only takes about a week to write up the whole proposal. My students help me do preliminary research and budget....They write up the part what we've done in the past, and I write up what we'd do in this project. Then we simply combine them together. (Nano-5, PI)*

The division of labour at the grant writing stage largely rests with principal investigators who alone are eligible to apply for most grants under current South Korean research funding policies.

Experiments and analysis of results: phase 3

Once scientists secure funding for a new research project, they start conducting full-scale experiments. This phase takes up approximately two-thirds of laboratory scientists' time (Latour and Woolgar, 1986). Phase 3 includes two sub-stages: (1) conducting experiments; and (2) data analysis. Because experiments are conducted by multiple participants assigned different tasks, all members in the lab should comply with both explicit and implicit norms and rules of the lab. Depending on the project size, experiments are conducted within a single lab or collaboratively across multiple labs.

Principal investigators play various roles throughout the research lifecycle, but it is the junior staff who carry out the actual operations under the general direction of the principal investigator. As scientists move up the ladder to that level, they move away from conducting the actual labour-intensive experiments, gradually losing their keen sense for lab work.

> *I gather, even the doctors don't know much when it comes to the more detailed procedures of experiments. They know the big picture but don't seem to be fully aware of specific operations. (Bio-6, Post-master's fellow)*

The principal investigator's role at the experimental stage is to give general directions and feedback to the junior scientists while making important decisions at critical points. Much of this information is communicated at lab meetings. The principal investigators preside over weekly or bi-weekly lab meetings, listen to the junior staff's progress reports, and provide further guidance. Lab meetings are a means by which the principal investigators orchestrate time management to complete the research project within the designated timeframe. In a large lab, mid-level researchers (e.g., senior research fellows, post-doctoral fellows, research professors) work as mediators between the principal investigators and graduate students. The mid-level staff report the experimental progress to their principal investigator and help junior colleagues by sharing tips and know-how for experiments.

Successful experiments are the primary concern of junior scientists. Many normative practices were identified at the experiment stage. Graduate students become full-fledged scientists by learning the norms and traditions of the lab. Successful experiments are directly linked not only to graduation but also to publishing in prestigious journals. They start their laboratory life by washing dishes for their senior colleagues, organizing reagents and apparatuses on the workbench, cleaning up equipment and completing other menial tasks, repeatedly carrying out experiments through trial and error, and learning research techniques from their senior colleagues. It is time-consuming, labour-intensive apprentice training. One post-master's fellow observed:

> *My seniors advised me a lot on what to do whenever I asked them why something wasn't working. They were very helpful in carrying out the experiment... so, you have to get their favour. You just have to have more interaction with them. Otherwise, it's hard to learn technical things about experiments and to get their advice. (Bio-6)*

This finding supports Haines *et al.* (2010, p. 78), who claim that '*graduate students learn research methodology, analysis of results, scholarly communication skills, and literature review skills from their mentors in their labs*'.

Phase 3 involves a variety of tools. Junior students use various information sources to find useful skills and techniques to conduct tests. When they do not know how to execute the experiments, they turn to formal (e.g., classic textbooks, the methods sections in journal articles) and informal (e.g., colleagues, online communities) sources. Most importantly, they seek help from their lab seniors and online Q&A sites. They heavily consult Biological Research Information Center, a popular online community among Korean bio-scientists. This informal source is handy and valuable for obtaining techniques and strategies for test procedures:

> *There's a lot you can't explain with words in bio-research experiments. So it's very useful to watch others in order to learn. The most effective way is to ask help from people who have done the same experiment before. Or, you go to [Biological Research Information Center] to get quick help, but there are also those things you can't exactly put into writing. So I think just going to talk to a colleague in the next room is the best solution. (Bio-10, Post-doctoral fellow)*

The detailed experimental processes are thoroughly recorded by junior scientists in the form of laboratory notebooks. Latour and Woolgar (1986, p. 69) regarded this dull activity as 'inscription', the nuts and bolts in the construction of scientific knowledge. Through this process, both individuals and the lab collectively are able to accumulate experimental techniques and skills. Often, an experiment might be terminated prematurely after investing great effort because of budget shortages or repeated failures. It is the principal investigators who ultimately make the decision, as one post-graduate student observed: '*When I wasn't able to make progress for a long time, my advisor thought I should take a different approach. So I had to drop it*' (Bio-6).

Upon obtaining satisfactory test results, scientists start analysing them:

> *Once you get the result, the next thing is to ask yourself, 'Why?' What does this result mean? You have to give scientific explanations other people can accept. (Bio-13, PI)*

Research quality is determined in this sense-making process. To ascertain the significance of their findings, both the principal investigator and the junior scientist who took the primary role in the experiment enter into a new stage where they work together closely, seeking and reading related literature and discussing the results. It is a more intellectual endeavour that comes after long, repetitive, and labour-intensive experiments. Thus, many principal investigators consider this seeking-meaning process as the most important task in the entire research lifecycle. This is the moment when all the work 'in the bench space will be forgotten, and the existence of laboratories will fade from consideration, ... and "ideas", "theories", and "reasons" will take their place' (Latour and Woolgar, 1986, p.69). Naturally, principal investigators take the leading role at this stage. The junior scientists assist the principal investigators in reducing the research data into a few graphs and figures to present their findings more effectively. As one interviewee noted, '*Good figures are very critical. It takes 4 or 5 figures to write a story*' (Nano-2, principal investigator). Latour and Woolgar also noted '*the eventual end product of such activity might be a highly valued diagram*' (p. 52). Thus, a good command of graphic software skills is critical to junior scientists at the data analysis stage.

Research product: phase 4

The fourth phase of the research lifecycle involves research output. When experiments are completed successfully, they are produced in the form of technical reports, source technology, patents, scientific journal articles, and industrialisation. In activity theory, these are considered as objects. Similarly, laboratory scientists in Latour and Woolgar (1986) considered paper production as the main objective of their activities (p.71). From graduate students to established scholars, the key index of a successful research product is publication in a prestigious international journal listed in the Journal Citation Report with a high impact factor score.

> *You get a score, something called IF. It determines the quality of your experiment. Nobody wants to publish their high quality experiments in Korean journals because that doesn't get you high IF scores. (Bio-15, PI)*

Again, many norms about the division of labour were observed in this phase. Principal investigators are in charge of all the major decisions on publication, including authorship (i.e., whom to include and in what order), the journal to submit, submission timing, revision, and resubmission. It is not uncommon to go through several revision processes. This entire process requires considerable effort, strategies, and a higher level of intellectual activity, which usually comes from experience. To publish in a prestigious scholarly journal, principal investigators should be able to communicate the meaning of their scientific discovery effectively to the broader scientific community through effective writing. Hence, scientists believe that success in research depends as much on the scientists'writing ability as on good research findings.

Most junior-level scientists lack publication skills and experience, especially in a situation where they have to prepare a paper in English. Unlike Indian scientists for whom publishing in English is rarely a problem (Sahu and Singh, 2013), for South Korean scientists, language becomes a huge barrier. Thus, principal investigators must take the lead. They write based on a very rough first draft prepared by their junior scientists. Therefore, it becomes a tremendous task for a principal investigator who has many graduate students. Writing often becomes a bottleneck in the production pipeline and results in lowering the productivity of the lab. The investigators tackle this problem using various strategies. Sometimes they hire professional editors who have experience in scientific publications. They may also invite a co-author with strong English composition skills. Additionally, the lab may hire an additional senior research fellow who has just returned from overseas with some experience publishing in English. All of these strategies can be considered as tools in the activity theory framework.

Graduate students also encounter great challenges in preparing to write scientific papers in English. They seek solutions by attending writing workshops offered by academic societies in their fields or by registering for private language schools to enhance their English writing skills. Tools employed by junior scientists in phase 4 also differ greatly from those used by principal investigators.

Evaluation: phase 5

The research lifecycle ends with the evaluation of research products.. While principal investigators normally give presentations, all scientists participating in the particular project prepare the research report for presentation to the funding agency. Upon fulfillment of the agency's requirements, the research products are evaluated in two other, more serious forms. The first form is the principal investigator's institutional evaluation. This annual evaluation involves salary, tenure and promotions, or termination of the appointment. The second form relates to evaluations by the funding system. That is, a successful research outcome correlates to a higher chance of securing funding again. This is the evaluation that the principal investigators are concerned about the most because science labs cannot continue without steady funding. The key to success is publication in high-impact journals. Again, publishing in a journal listed in the Science Citation Index with a high impact factor score is the norm in the current Korean science community, which absolutely and widely affects the scientists in all ranks. This tendency has been reported in earlier studies (Sahu and Singh, 2013). Post-doctoral fellows make enormous efforts to publish in high-impact journals to move up to permanent positions as principal investigators. For graduate students, publishing in a scholarly journal is linked to achieving the highest academic degree. This can happen only when principal investigators believe that the experimental results have met a certain standard.

Overall, the above research findings revealed a distinctive division of labour among the laboratory scientists. It also identified key research activities (RQ1) and information activities (RQ2) characterized by different work positions. The findings of the two research questions are constructed as a model of the labour division of the research and information seeking activities in the scientific research lifecycle (Figure 4). The kinds of activities and their strengths are indicated by the line types: the thicker and solid lines indicate that the corresponding actor constantly plays a key role. The finer and dotted lines indicate less central and intermittently participating roles. Appendix 2 further illustrates the division of labour among the laboratory scientists at each research phase in the activity theory framework. It shows distinctive roles played by scientists in different work positions. These findings demonstrate the usefulness of activity theory as a theoretical and analytical framework to understand the characteristics of scientists' information behaviour and division of labour in their community.

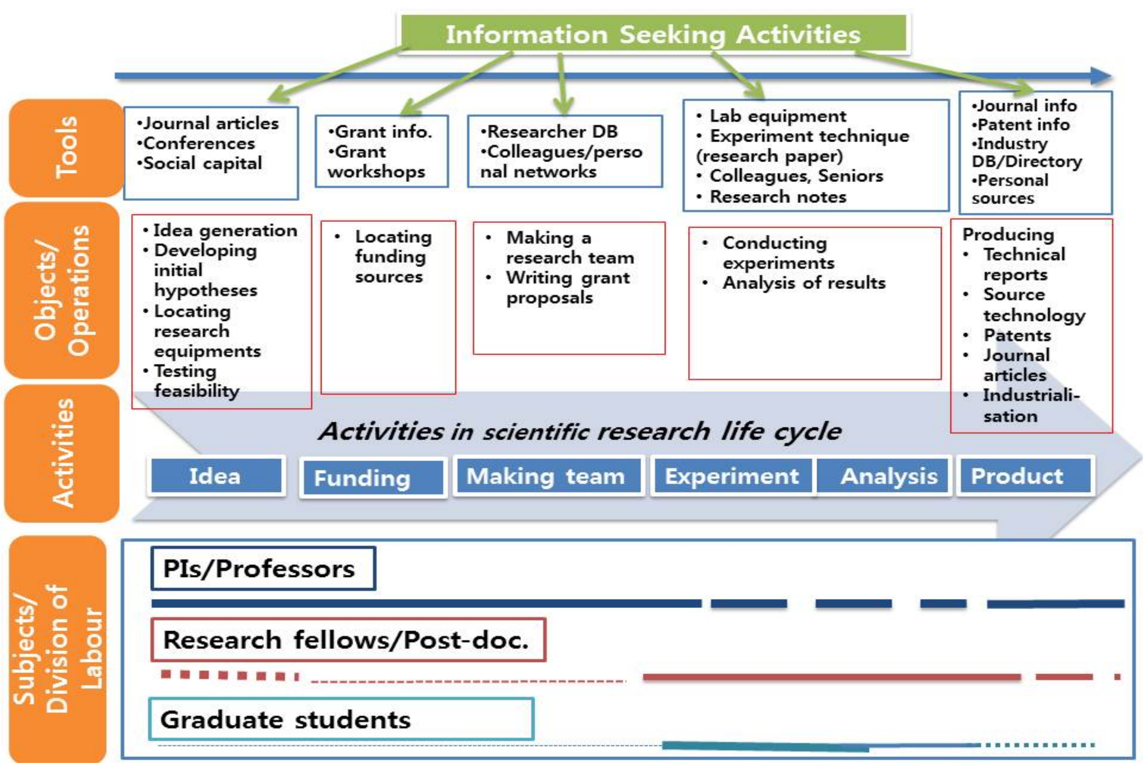

Figure 4: A model of division of labour in the lifecycle of scientific research activities

Discussion

Activity theory was found to be a useful conceptual and analytical framework guiding this study. What follows discusses the research findings from the framework of activity theory, particularly the nodes and the links in Engeström's diagram (Figure 2, Figure 3).

Scientists by work position: actor-division of labour-community

Laboratory research activity is performed by multiple actors in a science lab, individually and collectively through the division of labour in the community. The actors of laboratory research activity are scientists working in various positions in their research community through the division of labour.

As illustrated in Figure 4, it is the principal investigator who takes overall responsibility for initial idea development and funding: they hire a variety of staff members to work on their projects, including full-time research fellows, post-doctoral fellows and graduate students in M.A. and Ph.D. programmes. They lead research projects by taking full charge of the entire process; junior-level scientists are dependent, playing assistant roles. The only phase where their involvement is relatively weak is the experiment phase when junior members play the most active role. The junior scientists, mostly graduate students, play the nuts and bolts role; they produce experimental results and summarize the essence of the findings in effective images and tables.

In between the principal investigator and graduate students are post-doctoral fellows and full-time research fellows. Their roles in the lab differ by their subject expertise level and their years of employment in the particular lab. While their ideal role is to work as an intermediary between the principal investigators and graduate students, not every science lab has enough funding to hire them. They are not commonplace in most small- to medium-sized science labs in South Korea. Both the shortage of post-doctoral fellows and the frequent turnover caused by short funding cycles hamper the desirable roles of post-doctoral fellow. Short stays at one lab obstruct them from learning the culture and rules of the particular lab, which make it difficult to play anticipated roles.

> *Post-docs at many labs often do the same sort of work as graduate students do. They tend to get a slightly tougher topic than graduate students.... Usually their contract lasts for only a short time so those who come from other labs don't have much time to get accustomed to the lab. (Focus-group review session)*

This thin, middle-manager position can be regarded as a contradiction, a place to identify problems in an activity system and to intervene in the current practice by proper policy-making (Allen *et al.*, 2011). While this contradiction was identified in the division of labour among scientists, the problem is, in fact, rooted in the rules and norms node in activity theory because the problem is caused by the current short-term-based research and development funding and evaluation policy of the country. Theoretically, this finding shows the nature of the contradiction intertwined in the activity system. As a practical implication of the finding, policymakers in national science and technology might re-examine the current short-term funding cycle to strengthen the competencies of post-doctoral manpower.

The ways scientists behave by their position: norms, rules, tradition, and policies

The utmost theoretical usefulness of Engeström's diagram was found in the rules and norms node, from which notable findings were revealed. First, the contention that the community of laboratory scientists is built on strong norms is evidenced in information behaviour which is surprisingly similar to the behaviour of earlier generations (Hemminger, Lu, Vaughan and Adams, 2007; Palmer, 1991). Scientists' information behaviour in the networked environment has not changed much from the time when print journals were dominant. Contending the behavioural stability of scientists in the electronic information environment, Brown (1999) reported that all participants across various science disciplines continued to consider peer-reviewed journals as important, and thus they scanned the latest journal issues to stay current. This tendency still holds true in the present study, as the participants' information seeking and use are highly traditional and conservative. Two explanations are viable.

One explanation relates to the intensive nature of laboratory research. As reported above, laboratory research activity consists of a series of long repetitive, labour-intensive operations. There is also high pressure to complete the experiments and publish the results before other labs publish them. Junior scientists must focus their attention to maximize the efficiency of their work and therefore they marginalize all other activities. This tendency applies to information searching and management activities as they perceive them as secondary to experimental procedures (Roos, 2012).

The other explanation relates to the nature of the training process. Laboratory scientists begin their careers as lab assistants whose job description includes cleaning the lab and washing dishes. They learn experimental techniques and know-how from their senior colleagues, or by watching over the seniors' shoulders. They grow into the principal investigator position by embedding themselves with these norms and cultural practices. In this apprenticeship-style training, information-gathering activities, such as journal browsing, are transferred from senior colleagues and accepted as normative behaviour.

As another notable finding, this study uncovered that the norms and rules governing the science community affect the divisions of labour within and between labs. Within the lab, all members work under the direction of their principal investigators. Thus, a hierarchical relationship in apprenticeship training is a norm affecting relationships and communication mechanisms (Isha and Byström, 2016). On the other hand, the division of labour between labs showed a generally horizontal relationship, and each lab contributes its subject-- expertise to achieve a common goal. In this case, mutual trust is an important norm among research partners, especially at the principal investigator level, which affects the information sharing and communication between labs.

The influence of norms was also found in the younger principal investigators' research collaboration practices: they tend to feel that they are frequently victims of unjust credit sharing in authorship when collaborating with senior principal investigators as '*seniors tend to take advantage of juniors in our society, which...is not collaboration at all*' (Bio-15). This feeling unnecessarily restricts younger principal investigators' pool of viable collaborators to their peers or younger researchers, which was not reported in the Labour and Woolgar's US study. This practice can be attributed to the socio-cultural norm in a hierarchical society where younger, lower-ranking researchers are expected to submit to the authority of older and upper-ranking seniors. The term socio-cultural norm in this study refers to customs, beliefs, values embedded in the multiple layers of social and cultural environment where individual laboratory scientists are situated, which form their personal and social identity. A close reference of this concept of socio-cultural is Vygotsky's (1978) sociocultural theory of learning introduced earlier in the paper. An interviewee shared his experience of laboratory life in another culture as follows:

> *When I was doing my post-doc in Toronto, I envied their lab culture. The students were comfortably engaging in conversations with the boss, talking over coffee after lunch. Exchanging ideas freely, they often generated good ideas. I think lowering the communication barriers in our hierarchical lab culture would improve our research. (Bio-1, PI)*

He believed that hierarchical lab culture in South Korea caused communication barriers between the principal investigators and junior scientists. The socio-cultural norm prevalent in the South Korean science community reflects the hierarchical relationships and importance of seniority in the wider South Korean society (Lee, Chung and Kwon, 2012; Triandis, 1989).

Finally, the norms and rules node revealed two notable contradictions, a useful concept to identify problems in an activity system and to improve current practices. One is the contradiction between old tools and new rules. Most current information systems were developed in an era where performance evaluation was centred on publishing in academic journals. However, as the current science community more heavily emphasizes industrialised accountability, principal investigators are encountering challenges finding the latest information about the market, products, and technology to conduct collaborative research with the industry or transitional research for industrialisation. As one noted, '*the most difficult thing is to locate the company that I could work with to commercialize our source technology*' (Nano-8).

This issue indicates a contradiction between the tools (i.e., the academic-oriented information system) and rules (i.e., the latest research and development policy that emphasizes industrialisation and translational research). Regarding this contradiction, information providers could help principal investigators make practical, usable market information more widely available. It will be particularly important in the current climate of funding agencies, whose evaluation criteria is moving from a solely academic-oriented model to practical accountability to the real world (Allen *et al.*, 2011).

Another contradiction relates to short-term-based performance evaluation policies. In South Korea, the performance-driven evaluation system governs the entire research lifecycle. In particular, short-term-based research and development projects place unnecessary time pressure on principal investigators to complete projects in a short time period, which in turn burdens them to write new grant proposals. It forces them to conclude ongoing projects prematurely to produce quick products, which results in publishing papers in less prestigious journals.

> *Whether to chop the research piece by piece in those journals pushed by the evaluation system, or to wait until you get a good amount of data to publish in a good journal, it's your call.... To survive in this short-term review cycle, you have to submit to meet quantitative criteria although you want to publish in good journals. (Bio-1, PI)*

The time pressure and short-term-based performance evaluations are the key contradictions affecting the research activities and decision-making in the entire research process. From this contradiction identified in the norm and rules node, scientific policymakers could draw the practical implications of removing unnecessary barriers and anxiety from the research process. Harris (2008) advised information system designers to understand social, political, and cultural characteristics of a community when designing an information system. Harris' advice is highly relevant to studying laboratory scientists because their community was revealed as a strong normative community.

Information seeking and sources used: tools

In Engeström's diagram, *tools* is a node that includes everything scientists utilize to obtain intended objects. This node would receive particular attention from information scientists and system designers who are interested in providing optimal information systems and services. As Roos's (2012) study of molecular medicine researchers reported, the tools identified in this study were vastly diverse, and further differ by work position, research phase, and subject field.

Principal investigators' information seeking behaviour throughout the process is largely predictable and standardized. Their three most active information seeking activities occur during idea development, grant writing, and the research product in the lifecycle, which confirmed Roos's (2012) report. Key information venues include both formal and informal sources. The information needs for formal sources are mostly met by searching Google, the Websites of key journals, and the key databases. Principal investigators tended to believe that barriers to information access for written literature no longer exist because they think everything is on the Internet. This finding, however, holds true only for the information-rich institutional users who can access most literature directly from their desktop. The key information activity of principal investigators conducting top-notch research is to build a strong personal network through meetings with fellow scientists and exchanging ideas at international conferences (Nano-1). They had very open and broad personal networks with domestic and international fellow scientists. Such information exchange activities lead principal investigators to encounter new research ideas and possible collaborators who can offer synergy to their research and share insider information for funding. This finding confirms the comparative importance of interpersonal sources and conferences among the older academics (Sahu and Singh, 2013).

A related, noteworthy finding is the way principal investigators communicate with others. Even if they use high-level technologies for their research, their communication style remains traditional as many '*prefer talking in person*' (Nano-2). They continue to meet in person, call, and e-mail constantly. They believe in the mutual trust developed through face-to-face communications in scientific collaborations, and for them, social media cannot substitute for such trust. Similarly, principal investigators choose secure and traditional face-to-face methods of communication over mediated communication, such as social media, because of their security concerns. They tend to use digital communication tools only with the people in their personal networks. These selection tendencies demonstrate that certain scientific activities constrain the use of information tools, because of secrecy (Latour and Woolgar, 1986). That is, the scientists' use of social media is limited by certain rules and norms (i.e., trust, security, secrecy) governing the community.

For junior-level scientists, their information activity became vigorous and self-directed during the experimental phase as the principal investigator's central role receded. The general notion of slow information activities during the experimental stage seems to apply to principal investigators only, not to the junior level. Junior scientists engage in active information seeking and use activities to solve problems during the experiments. For literature searches, students heavily rely on Google, employing rudimentary search techniques (i.e., simply entering several subject keywords). Another heavily utilized source is the homepages of the key journals in their field, either by entering the URLs directly or by Google. They also search for analytical tools and image analysis software to present their findings effectively. There have been efforts to develop a subject-specialized social media tool, such as myExperiment, but the younger generation did not seem to regard generic social media as research tools; one Ph.D. student (Bio-8) said, '*I know many researchers who use it very actively. But I think it's mostly just for personal matters. Nobody I know uses it for research*'. This ambivalent picture about social media addresses a need to continue monitoring social media use for research as it further penetrates society.

Unique to the science field, lab meetings are another important venue for principal investigators and junior scientists to exchange information. Besides checking on the progress in experiments, principal investigators ask junior scientists to report about notable new work published in the latest issues of key journals that they were assigned to monitor regularly. By monitoring the most current research trends in the key journals, the entire lab as a community can engage in environmental scanning. For a principal investigator who often has difficulty in keeping up with the research in his or her field because of a lack of time (Murphy, 2003), lab meetings are an effective way to delegate routine research tasks to supporting staff.

Conclusion

This study was conducted to investigate the characteristics of research activity and information behaviour within different work positions in the scientific research lifecycle. The conceptual framework of activity theory, integrated with the research lifecycle, enabled the systematic delineation of research and information activity contexts. Below outlines the theoretical and practical implications of the findings.

From a theoretical perspective, this study confirmed activity theory as a useful framework to study individuals working collectively (Allen *et* *al.*, 2011). Engeström (1999) referred to this as *knotworking*, meaning that loosely connected actors become tied together and untied. Both individual researchers and the science lab as a whole were collaborating and building their own research skills when working to achieve a common goal: a scientific discovery. Scientists in different work positions played distinct roles in this process. The six nodes in activity theory were useful analytical tools to reveal the nature of the laboratory scientists' division of labour, the tools utilized by different actors for different purposes, the norms underlying the activities affecting the roles, the division of labour, and the unique culture of the science community. Delving into the unexplored concept of work position, the study was able to reveal all of this contextual information, which is critical in shaping the scientists' information behaviour. These findings were effectively constructed in the model (Figure 4) that demonstrates how the work position affects research and information seeking activities of scientists in different positions in the research lifecycle.

From a practical perspective, this study offered a contextual understanding of the everyday research practices of laboratory scientists in different work positions. Scientists in differing positions used a wide range of information sources for a variety of purposes throughout the research lifecycle. Thus, it is critical for system designers and policymakers to design scientific research support systems based on a proper contextual understanding of laboratory scientists' everyday work practices and their beliefs, norms, rules, policies and culture governing the laboratory and larger scientific communities. Such contextual information could help suggest specific points of service and relevant content for target users when designing research support systems.

Finally, this study found some phenomena that could not be fully explained in the study. According to this study, laboratory scientists work in a strong normative community. Of particular importance are socio-cultural norms and tradition; South Korean laboratories in particular must confront certain socio-cultural norms that can impede some types of collaborative research and easy communication between scientists positioned in different places within the organizational hierarchy. Considering the fact that the present study was qualitatively conducted in the societal and cultural context of South Korea, the findings may be bounded by the norms rooted in the country's Confucian tradition that views human relationships as hierarchical (Cheng, 1990). This finding warrants further investigation in other socio-cultural contexts to assess the trustworthiness of the findings, especially the prevalence of strong hierarchical relationships. Such an investigation could be conducted in other East Asian countries, where the Confucian tradition is also influential. It would also be worthwhile to undertake a study in a western society to verify whether the hierarchical nature of working relationships is a culturally-bounded or a universal phenomenon of apprenticeship training. The results would further ascertain the similarities and differences in the roles defined by work positions and the influences of norms across different socio-cultural contexts. Collective information behaviour observed in complex professional workplace activities, such as those of laboratory scientists, could be further uncovered through continuing exploration of the effect of work position.

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About the author

Nahyun Kwon is a Professor in the Department of Library and Information Science, Myongji University, 34 Geobukgol-ro, Seoul, South Korea. She received her Ph.D. degree in School of Library and Information Studies from University of Wisonsin-Madison. Her areas pf research relate to human information behaviours, public library outcomes, and impact of library services on society. She can be contacted at: nahyun.kwon@gmail.com

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Appendices

1. Demographic background of each research participant (Opens in a new window)

2. Research activities by work position in the research lifecycle (Opens in a new window)

4 2 Last updated: 27 February, 2017