Factors and Implications for Creative Scientists: A Systems View of Creativity

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ABSTRACT

This study examines three factors - personal, academic features and governmental research environment - that influences the research of creative scientists based on a Systems Model of Creativity and tries to deprive policy implications. First, this study investigates the characteristics of creative scientists' research through a literature review. Next, it analyzes the features of academic characteristics, and creative research environments by the interviews of nine creative scientists in Korea. Lastly, it draws its implications and analyzes the limitations of this research.

KEYWORDS: scientific creativity, creative scientist, systems model of creativity

1. INTRODUCTION

The concept of "creativity" is a new buzzword with the emergence of a creativity-based society in the 21st century. The European Union proclaimed 2009 as the "European Year of Creativity and Innovation" and the World Future Society held in Chicago in July 2009, was based on the theme of "Creativity and Innovation". At the 10th World Knowledge Forum held in October 2009, Gary Hamel noted that the world was moving from a knowledge-based economy to a creativity-based economy that emphasized the future importance of "creativity".

The concept of creativity influences many fields that include education, industry, and research. The emergence of "Creative Education" in the field of education (Cropley, 2001; Cropley and Cropley, 2009; UNCTAD, 2008), "Creative Class" and "Creative Industry" in the industrial sector (Florida, 2002, 2007), and the building of a "Creative Research Environment" in the research area

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(Hollingsworth, 2006; Heinze et al., 2007; Hemlin et al, 2004) are relevant current issues.

With the recognition of Science & Technology as important for the enhancement of national competitiveness, there is an increasing interest in the nurturing of creative scientists and the creation of a creative research environment. Advanced countries are pursuing various policies to support research, such as Transformative Research (NSB, 2007), Frontier Research (EC, 2005), and Breakthrough Research (Academy of Finland, 2007). The Lee Myung Bak Administration of Korea has stressed the importance of original research with a focus on building a creative research environment to support high-risk and high-return research activities (MEST, 2009).

Past research on creative scientists focused on studying personal characteristics (Simonton, 2004: 99) or identifying organizational factors (Heinze et al., 2007; Hollingsworth, 2006), but there are limited studies on identifying the features of a creative research environment at the government level (Heinze and Bauer, 2006). As a result, the real situation and the policies were ineffective because a gap existed between the policies to nurture creative scientists and to shape a creative research environment. The reason why they were differentiated from policies for general scientists remain unclear. In particular, there was an inclination to pursue generic policies despite the fact that policies could differ according to the type or academic characteristics of research projects conducted by scientists (Kim, 2009).

This study examined the personal and academic characteristics that influence the research of creative scientists and the features of the government research environment from a systems model of a creativity perspective to produce future policy implications. The results of this study will provide the theoretical basis for the establishment of scientist-related policies and act as the impetus to create differentiated policies. Chapter Two examines the systems model of creativity (the analytical framework of this study). Chapter Three identifies the factors and characteristics of a creative scientist through a literature review. Chapter Four features interviews with nine Korean creative scientists and is the basis for analyzing the academic characteristics of the creative research environment for the future development of relevant policy implications. Chapter Five discusses the findings and limitations of the study.

2. ANALYTICAL FRAMEWORK: SYSTEMS MODEL OF CREATIVITY

The Systems Model of Creativity by Csikszentmihalyi (1996) is a useful tool for the study of personal and academic characteristics that affect the research activities of creative scientists and the features of a government research environment. According to the Systems Model, creativity is generated through the interaction between three systems: the person, field, and domain. In the Systems Model, although the "person" is an important factor, more focus is placed on the field and domain factors. The "person" refers to the individuals that create new ideas. "Field" is a group of people that evaluate and acknowledge the creativity of an idea. The range includes the human community surrounding

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[1] "Five-Year Assessment of the European Union Research Framework Programmes.", DG Research, 2004 and 2009.

[2] See footnote 1. Note that due to space limitations we refrain from the presentation of methodological details for both the quantitative and qualitative analyses. We rather concentrate on the presentation of research results. The interested reader in the analytical methodology and detailed variable exposition can consult the (extended) final report and other documents of the InnoImpact study from the website and from the authors of this paper.

a "person" along with the entire social and cultural systems that influences activities. Lastly, domain refers to the symbol system that encompasses an academic field taught to successive generations of scientists.

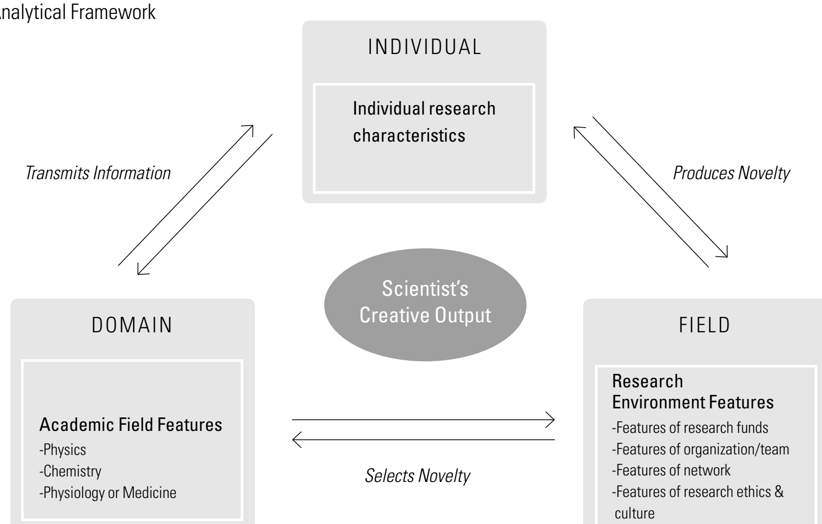
For a person to exhibit creativity, they need to be transmitted with a set of rules and practices from the previous domain to be able to create a novel variation that must be selected by the field. Creative ideas must also go through the process of "variation-selection-transmission" similar to the evaluation theory. According to the Systems Model, creativity is any act, idea, or product that changes an existing domain or transforms an existing domain into a new domain. Furthermore, the definition of a creative person is someone whose thoughts or actions change or create a new domain (Csikszentmihalyi, 1996, p. 28).

An examination of the process of creativity based on the definitions of the factors of the Systems Model shows that the creative idea of a person cannot be creative by itself. Only those ideas that have been verified as creative by people in each field are entitled to change, expand, and intensify the existing domains.

The creative discoveries of scientists are complex outputs of the individual creative attributes of a scientist, the characteristics of the academic field that the scientist belongs to, and scientific communities or government policies that motivate and evaluate the achievements of a scientist. It is necessary to analyze and identify the three characteristics mentioned above to understand the factors that affect creative scientists.

This study will examine the personal characteristics of creative scientists through a literature review and analyze the interviews with the nine most representative creative scientists in Korea to understand the features of the academic field and the on-site environment. The academic fields are categorized into 'Physics', 'Chemistry' and 'Physiology or Medicine', as categorized by the Nobel Prize awards in science. The on-site characteristics will be studied based on the factors of the research environment of a creative scientist, such as research funds, research organization/team, network, research ethics, and culture.

FIGURE 1 Analytical Framework



Source: Csikszentmihalyi (1999: 315) complemented.

3. CHARACTERISTICS ANALYSIS OF CREATIVE SCIENTISTS: LITERATURE REVIEW

3.1 Concept and Factors of Creative Scientists

The most critical factor that influences the research of a creative scientist is the nature of their research. Studies on the personal characteristics of creative scientists have been a part of the psychology of science (Simonton, 2004). Previous studies in this field focused on understanding the characteristics and backgrounds of creative scientists by applying psychometric assessment techniques to current scientists (Feist, 1998; Mansfield and Busse, 1981; Simonton, 1988). Although this study contributed to the identification of the cognitive characteristics of creative scientists, the traits or behaviors related to their individual research were not covered.

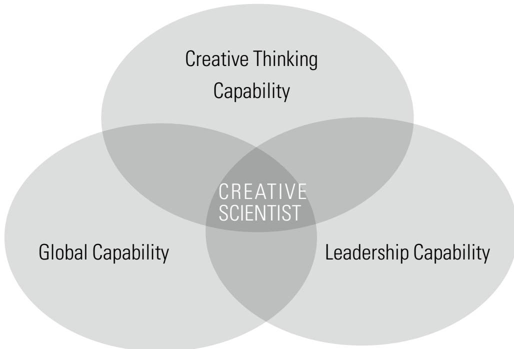
Studies on the definition of the concept and composition factors of creative scientists are lacking. In traditional terms, creative scientists refer to scientists with creative thinking capabilities. However, creative scientists are required to have a greater capacity to match globalization trends. Scientists need to possess creative a thinking capability on a personal level and must have a global leadership capability. The attributes of a creative scientist include creative thinking, global skills, and leadership capabilities.

Creative scientists have creative thinking capability to create new understanding, useful ideas, and produce results. In science, the five creative thinking factors by Guilford (1985) are noted for the effective categorization of "creative thinking". Guilford considers "sensitivity to a problem", "fluency", "flexibility", and "originality" of thinking and "elaboration" as elements relevant to creative thinking. "Sensitivity to a problem" is the ability to find problems in daily surroundings and respond sensitively to them and the "fluency of thinking" is the ability to spontaneously develop numerous ideas and solutions to a problem. "Flexibility of thinking" is the ability to change fixed ways of thinking or the perspective of a certain problem and "originality of thinking" is the skill to bypass established patterns and create original ideas. Lastly, "elaborative thinking" is the ability to express an idea in a detailed and systematic way. Therefore, creative thinking is the capability of a creative scientist to effectively utilize these five attributes.

Secondly, creative scientists need to acquire a global capability such as communication and networking skills. In order to be recognized for ingenuity, a creative scientist needs to effectively promote achievements and continuously communicate with global experts who can help refine ideas. This scientific collaboration requires linguistic and effective communication skills. The increasing complexity and convergence of knowledge and technology in the 21st century requires a continuous interaction with external knowledge. In particular, big science fields such as Particle Physics require large-scale equipment, specialized human resources, and significant funds; consequently, a networking capability is often the barometer determining the research capability of an individual. The building of a global networking capability is essential for the production of creative results.

Thirdly, future creative scientists must possess leadership capability. The continuing complexity and convergence of the scientific environment makes individual research difficult and increases the need for collective research. This is shown by the increased in big science and joint awardees of the Nobel Prize for Science. Leadership capabilities are required to form collective research groups, derive voluntary cooperation from members, and produce creative results. A capacity to undertake personal research, the capacity to effectively lead a group, and form a greater global achievement is required for successful research. The fostering of a leadership capability to manage global network teams is increasingly important in the development of creative scientists.

FIGURE 2 Factors of a Creative Scientist



3.2 Characteristics and Implications of Creative Scientists

An analysis on the behavior of creative scientist towards research offers implications in the government establishment of a research environment to nurture creative scientists. According to the creativity theory, creative scientists share the following traits.

First, more than 10 years of intensive education is needed to acquire a specialty in a certain field (Gardner, 1993; Ogle, 2007). The analysis of seven creative thinkers by Howard Gardner revealed that 10 years of preparation was essential for the generation of creative achievements and that creative results were being produced every decade. This implies that continuous support is imperative in the nurturing of creative scientists.

Second, creative scientists are often exposed to the frontiers of knowledge in their academic fields (Ogle, 2007; Csikszentmihalyi, 1988). For instance, Watson and Crick had the chance to encounter the prominent biochemist of their time who was pondering the structure of DNA, and they could apply their geometric knowledge to Biochemistry. This shows that meeting with world-renown scientists at the research phase is very important in solving problems.

Third, creative scientists experience "flow", which is a state of complete engagement during research (Csikszentmihalyi, 1988) and a state where the mind is pre-occupied with solving the problem. When asked how he discovered the 'Law of Gravity', Isaac Newton replied that he thought of only one thing until he came up with the answer. This suggests the importance of a research environment that enables scientists to become fully engaged in world-leading research.

Some common features of creative scientists such as Nobel Laureates are as follows: First, the achievements of creative artists are mostly produced in their twenties and thirties. Einstein published his "Special Theory of Relativity" and "The Photoelectric Effect" at the age of 26, while Max Planck published his research on the "Quantum Hypothesis" at age 32. This creativity identifies a need to support young scientists because there is a higher possibility for scientists to produce creative results in their 20s and 30s.

Second, it takes more than an average of 10 years from the time of scientific discovery to the awarding of a Nobel Prize in the sciences. The three Japanese Laureates of the 2009 Nobel Prize in Physics published their research results during the 1960s-1970s, some 40 years before they were awarded for their work. This implies that even if scientists managed to make a scientific discovery at an early age, it takes a long time to verify the value of the achievement and that short-term assessments of achievements in the field of basic sciences is inappropriate.

Third, it is more common for scientists to be jointly awarded prestigious prizes in science. Theories that win the Nobel Prize must be proved through experimentation and is the reason behind the rise of joint awardees. This is shown by the fact that 48.6% of Nobel Prize laureates in science were joint winners. Joint research with prominent scientists is increasingly important in producing world-class achievements.

Fourth, the number of successive research projects between students and their mentors are on the rise. In general, new theories in basic sciences require the development of new techniques for their verification and it is common for students to continue to develop the initial research of a mentor. In the past, about one half of all Nobel Prize awardees in science laureates were students of previous Nobel Prize winners, and Enrico Fermi and Niels Bohr each produced six and four students, respectively, that also won the award. This illustrates the importance of the formation of research associations in the creation of world-class results and the promotion of successive research activities.

Lastly, according to Gladwell (2008), successful outliers (in addition to scientists) share the following characteristics: First, it takes at least 10,000 hours of preparation for a person to become an expert in a certain field. This suggests that producing creative accomplishments in a certain field require continuous interest and investment.

The second trait is that the social and cultural environment surrounding a person has a great influence on the production of creative results. Gladwell states that the power of cultural legacy is strong and deeply rooted with a significant impact on the success and failures of outliers. A cultural legacy is critical in the formation of a creative research culture. Creative achievements in science and technology tend to be maximized when a scientist devotes more than 10 years to concentrated study, when they are exposed to the frontier knowledge of a certain field, and when they are in a creative research environment where they can become fully immersed in studies. It is highly relevant for the government to devise policies to provide systematic support.

TABLE 1 Characteristics and Policy Implications for Creative Scientists

Characteristics	Policy implications
• More than 10 years of concentrated study	• Concentrated training and investment required
• Exposure to frontier knowledge of a field	• Need contact with frontier knowledge
• Extreme immersion	• Need to create a fully immersive environment
• Creative scientific discovery made in 20s-30s	• Need to support new scientists
• Some 30-50 years since release of scientific findings to awarding of prize	• Need to provide mid-long-term support to research
• Rising trend in joint awardees	• Need to encourage more team research activities
• Increase of successive research between student and mentor	• Need to build leadership capacity
• More than 10,000 hours of preparation required	• Need to form a creative research culture
• Importance of social and cultural surroundings	

4. AN ANALYSIS OF THE FEATURES OF ACADEMIC FIELDS AND CREATIVE RESEARCH ENVIRONMENTS: AN ANALYSIS OF NINE KOREAN CREATIVE SCIENTISTS

Another factor that influences the research of a creative scientist is the academic field (Whitley, 2000) and the characteristics of a government research environment (Heinze et al, 2007). An analysis of the academic features and the research environment factors of a certain scientific field are required for the development of policies to promote the achievements of creative scientists. This study conducts an analysis of interviews of nine creative scientists in Korea. An examination of the methodology and analysis results is made below.

4.1 Research Methodology

This study conducted an analysis of nine creative scientists in Korea in the investigation of how the features of an academic field and a creative research environment influence research by creative scientists. The interviews were conducted through a semi-structured questionnaire from September 16 to November 19, 2009.

To develop a creative scientist model, we relied on the winners of the National Scientist Award (the most distinguished science prize in Korea), the Top Science and Technology Award, Junior Scientist Award, Creative Research Initiatives Award, Hoam Science Award, and potential candidates for the Nobel Prize. In addition, interdisciplinary models were selected in Physics, Chemistry, Physiology, or Medicine, the categories of the Nobel Prize in science fields for a comparison and analysis of features of different academic fields. To explore the characteristics of research environments by different phases of experience, we examined a broad group of creative scientists from mid-career stage (35 years-50 years), late-career, and decline stage (50s-retirement) according to Hall (1976). The final nine creative scientists that were selected for the interview are distributed in the following groups with the following characteristics.

FIGURE 3 Characteristics and Distribution of Creative Scientists

Career stage — Late-career & decline / Mid-career

scientific disciplines			
PHYSICS	SOO-BONG KIM	HAN-WOONG YEOM	EUN-SEONG KIM
CHEMISTRY	RYONG RYOO	SU-MOON PARK	HEE-CHEUL CHOI
PHYSIOLOGY OR MEDICINE	ZANG-HEE CHO	KYU-WON KIM	EUN-JOON KIM

The focus of the interview was to identify the four environmental factors that influenced the characteristics of an academic field, the research phase (or the research funding), research organization/team, network, research ethics, and creative culture. In order to have a better understanding of the features of a creative research environment, the analysis was made more specific to deal with intervals between the production of core accomplishments, frequency of a change in research fields (continuity), size of investment of early research activities, and the need for research ethics and a creative research culture. The results of the study are explained in detail below.

[1] I would like to thank to Dr. Hyoungjoon Jeon, Dankook University and Dr. Woo-Sung Jung, POSETCH for helping interview the creative scientists.

TABLE 2 Characteristics and Distribution of Creative Scientists

Scientific Disciplines	Name	Major	Age	Last Baccalaureate Organization	Affiliation	Selection Criteria
Physics	Soo-Bong Kim	Particle Physics	50	MIT	Associate Professor, Seoul National University	• Top 15 Most Cited Author in Physics, ISI • 1989 Rossi Prize, American Astrological Society
	Han-Woong Yeom	Surface Physics	44	Tohoku Univ.	Associate Professor, Yonsei University	• Creative Research Initiatives Award • Science and Technology Award
	Eun-Seong Kim	Low Temperature Physics	39	Pennsylvania State University	Assistant Professor, KAIST	• Lee Osheroff Richardson Prize • Creative Research Award
Chemistry	Ryong Ryoo	Solid State Chemistry	55	Stanford University	Professor, KAIST	• National Scientist Award • Hoam Science Award
	Su-Moon Park	Electroanalytical Chemistry	69	University of Texas at Austin	Professor, UNIST	• ISI Highly Cited Researcher • Sudang Award
	Hee-Cheul Choi	Solid Inorganic Chemistry	39	Purdue University	Associate Professor, POSTECH	• Junior Scientist Award
Physiology or Medicine	Zang-Hee Cho	Nuclear Physics	74	Uppsala University	Director, Neuroscience Research Institute	• Distinguished Faculty Award for Research, University of California, Irvine • Member elected, The US National Academy of Science
	Kyu-Won Kim	Angiogenesis	58	University of Minnesota	Professor, Seoul National University	• Hoam Science Award • Top Scientist Award
	Eun-Joon Kim	Molecular Neurobiology	46	Michigan State University	Professor, KAIST	• Junior Scientist Award • Creative Research Initiatives Award

4.2 Study Results and Implications

4.2.1 Characteristics of Academic Fields: This study conducted an interdisciplinary analysis on the size of major equipment, the investment in early research expenses, and the number of co-authors published in journals. According to the results, the fields of Physics, Chemistry, Physiology or Medicine belonged to the same scientific sector, yet there was a great difference between them. In particular, even in the same academic field, sometimes the gap between sub-academic fields was so great that they overshadowed the gap between the academic fields.

Physics is a field that requires larger-sized equipment than Chemistry, Physiology, or Medicine. Big science fields such as Particle Physics can require the use of an accelerator that cost up to hundreds of millions of dollars. Surface Physics and Low Temperature Physics require the use of a beamline, an accelerator that can cost billions of dollars, and vibration-free laboratory facilities. On the other hand, the fields of Physiology or Medicine require comparatively small-sized equipment that cost tens of millions of dollars, such as a particle counters, synthesizers, and special microscopes. However, fields based on theoretical research within the Physics sector cost relatively less compared to the other two sectors. Therefore, making standardized judgments in different academic fields is impractical.

Due to such different academic features, the early research expenses of each academic field differ by sub-academic field. For instance, the early research expenses (including eq uipment costs) for a newly appointed professor who is beginning research are around one hundred thousand to one million dollars in the field of Physics. However, in Chemistry the expenses are around 100-200 thousands of dollars, and in Physiology or Medicine, around 10-500 thousands of dollars (excluding sectors such as Nuclear Physics and Electronic Physics).

There was also a significant difference in the size and recording method of co-authors by academic field. For instance, in Particle Physics, the co-authors of a thesis project led by Professor Soo-Bong Kim ranged from 30 to 500 individuals, whereas the project in the field of Solid Chemistry led by Professor Ryong Ryoo was composed of 3 - 20 individuals. The Surface Physics project led by Professor Han-Woong Yeom and the Low Temperature Physics project led by Professor Eun-Seong Kim are composed by up to 5 individuals on average. The recording method of co-authors in the journals also differs by academic field. For example, in many journals dealing with Physics (such as the Physical Review Letters), the name of co-authors are recorded in alphabetical order and the titles of first author or senior author are irrelevant in such theses. In contrast, the names are recorded by the order of contribution in other academic fields.

These aspects lead to the following policy implications: First, early research expenses vary by academic field, so the government needs to differentiate the amount according to different fields in the calculation of seed research grants. Second, the majors in each academic field may have different funding requirements. Allocating the same level of expected research budgets for each major could create problems. The government needs to consider these issues when establishing the budget for research expenses and R&D. Third, the number and need for co-authors (which are a basic factor in each field) vary by academic field and the government needs to consider this when implementing a collective research project. Fourth, even SCI-level journals differ in the way co-authors are recorded. Consequently, these points should be considered in the assessment of achievements based on journals. Otherwise, it may lead to distorted results and impair confidence in the assessment system.

4.2.2 Intervals Between Productions of Core Accomplishments:

This study conducted an analysis on the frequency of the production of core accomplishments and the intervals between them in order to understand how much time and effort are devoted to world-leading achievements by creative scientists. 'Core accomplishment' refers to a widely recognized achievement that is the most original and worthwhile accomplishment of a scientist. The interview revealed that about 7-10 years was dedicated to the process, although some differences exist according to the academic field of the researcher. The "10 year's Pendulum of Creativity" and the "10,000-hour Rule" applied to the study seem appropriate (Gardner, 1993; Gladwell, 2009).

There were some differences between academic fields. In the case of Professor Soo-Bong Kim of Physics and Professor Ryong Ryoo of Chemistry, and Dr. Zang-Hee Cho of Physiology or Medicine, who were in their late-career and decline stage (50s-retirement), it took around seven to ten years. Meanwhile, in case of Professor Eun-Seong Kim of Physics, Professor Hee-Cheul Choi of Chemistry, and Professor Eun-Joon Kim, who were in their mid-career stage (35 years-50s), it took an average of six years, three years, and five years, respectively. However, the accomplishments by the three new researchers do not fit the category of world-leading achievements. Therefore, there is a limit to the generalization of research periods by new researchers.

The above analysis results provide the following implications: First, world-leading accomplishments may differ by academic field and individuals; however, on average it takes seven to ten years. Therefore, in order to encourage more world-leading accomplishments, it is necessary for the government to provide mid-long term reliable funding. Second, majors under the same academic field may differ in the time consumed in producing world-class accomplishments. Thus, it would be necessary to note the existing differences when planning the size of research funding. For example, it takes 10 years to produce such a result in the case of Particle and Surface Physics, whereas in Low Temperature

Physics (which belongs to the same academic field) it takes only about six years. In the field of Chemistry, it takes about10 years in the fields of Solid State Chemistry and Electroanalytical chemistry; however, it only takes around three years in the case of solid inorganic chemistry.

4.2.3 Frequency of Change of Research Field (Continuity): This study examined the frequency of change in research fields to examine how immersed in a certain theme a creative scientist becomes to produce a world-class achievement. The change of research field refers to a change of field where the related knowledge and research methods of the scientist are significantly different from the original field of study. The interview showed that regardless of academic field, almost all scientists concentrated only on one area, and sometimes scientists changed their fields in order to become more independent from the research area of a mentor or because of an intellectual curiosity in new areas. For instance, the research on neutrino currently conducted by Professor Soo-Bong Kim of Physics first began during his doctoral program (1986). He concentrated only on this theme, managing to successfully observe neutrino (1987), produce core accomplishments such as the discovery of top quark (1995), the neutrino oscillation (1998), and conducted research on neutrino mass (2005).

There was also a case of a career change of field of study during research. Professor Ryong Ryoo of Chemistry was appointed assistant professor at KAIST at the age of 33, and until he reached 38, he continued to research a theme that was in line with his doctoral study (identification of catalyst characteristics). However, at age 38 he came across a paper on chemical compounds in the journal Nature written by another researcher and decided to move away from conducting research on ready-made catalysts to a different field of creating catalysts.

Most world-renown scientists focused on one theme since their doctoral programs or changed the field of research only once. Those who changed research fields were not motivated by the easy acquisition of research grants but desired to become world-class scientists or because of a scientific curiosity towards a new field of research.

These results have several implications. Scientists producing world-leading accomplishments tended to be continuously engrossed in one field and the cases of "research migrants" (who change research fields to win grants) were rare. This implies that in case of research grants, the government should enable scientists to conduct continuous research on a certain theme. In particular, governments need to trust and sponsor scientists whose research capability has been verified on a global level even if their themes seem to be along similar lines.

4.2.4 Extent of Connection With Research Funds: This study undertook an analysis of the source of research grants and the extent of connections between research funds in order to understand the difficulties of creative scientists in acquiring research funds for the process of conducting research. According to the results, scientists experienced greater difficulty in acquiring funds early in their careers. It was relatively easier for creative scientists to win research grants compared to general scientists, although there were intervals between research grants that made the situation difficult at times.

Professor Ryong Ryoo of Chemistry points to the lack of research funds as the greatest difficulty during the earlier years of his profession. In 1987, as a newly appointed professor he remembers receiving 2,000 dollars a year (equivalent to about 20,000 dollars in modern terms) in research funds, but it was not sufficient to conduct expensive research in Chemistry. However, he said that he soon received 3,000 dollars a year for research (over two years) from the Science and Engineering Foundation and another 5,000 dollars in oriented basic research, this and some other incentives allowed him to manage around 10,000 dollars of research funds a year. Yet, this was still not enough compared to the costs needed for research. On the other hand, Dr. Zang-Hee Cho of Physiology or Medicine recalls the particular difficulty of acquiring research funds to conduct research in a big science sector. While he was working at KAIST in 1985, the government contributed 400,000 dollars (a significant amount considering the economic situation of Korea at the time). However, he almost had to give up developing 2 Tesla MRI because he was unable to receive an additional 200,000 dollars in research grants. He remembered working hard to acquire private funds and barely managed to develop the 2 Tesla MRI. In addition, Professor Han-Woong Yeom notes the difficulty creative scientists face when funding is finished and there are few incentives for funding a follow-up program.

According to an analysis of major research funding sources of world-leading domestic scientists, most researchers mentioned the Science Research Center (SRC) or Creative Research Initiative (CRI) as helpful for their research. These two initiatives are both long-term projects of over nine years that enabled scientists to conduct various experiments during the sponsorship period. Although SRC projects are often criticized as having the same problems as collective research programs, world-leading scientists state that these projects provided the most effective environment in undertaking stable and mid-long term research.

The above analysis results suggest the following policy implications: First, it is important to provide novel researchers with early research support. It is desirable that the government works to provide research grants to new researchers. Second, the size of early research funds varies by field and must be taken into consideration when calculating the size of research support. The calculation of research grants should consider the unique features of fields that require large-scale equipment such as big science or expensive research fields. Third, the connection between research funding programs must be strengthened. When specific funding programs to an individual researcher expire, they should be able to receive support for follow-up programs when the research capability of a researcher is verified or a program should be established so that they can continue to apply for additional program funding.

4.2.5 Characteristics and Size of Research Team: This study examined the size and characteristics of a research team in order to understand the features of the formation and operation of a research team during the research by creative scientists. The sub-academic fields showed a difference in research team sizes and features.

Big science fields such as Particle Physics have similar aspects to corporate-style organizations. The size of the research team to which Professor Kim belonged during his doctoral thesis was around 30 individuals, but his research team during his studies at Michigan University totaled 450 individuals. The research team currently studying Particle Physics is a global team of some 150 individuals. Fields like Particle Physics that require large equipment such as accelerators also require a large number of researchers.

In contrast, the Solid Chemistry research team led by Professor Ryong Ryoo includes about 20 individuals composed of graduate students and post-docs. The team is again divided by theme and three to five researchers conduct research based on a common theme. Such small-numbered teams are quite common in the fields of Chemistry and Physiology or Medicine. However, the team led by Professor Zang-Hee Cho of Physiology or Medicine conducts research related to the field and includes engineering that builds equipment and it requires many researchers with interdisciplinary knowledge. This is why Nuclear Physics research (which invents new equipment) is generally conducted through the entity of an independent research institute.

The research team is composed of students in their graduate and doctoral programs and post-doc researchers regardless of academic field. However, with the increase of students going abroad for their studies, the task of finding skilled students and post-doc researchers is becoming more difficult. Recently, this is attracting more students from Southeast Asia to replace them. Professor Ryong Ryoo states that researchers would produce greater results with more intelligent doctoral program students and capable post-doc researchers.

The above results lead to the following implications: First, the government needs to differentiate the amount of funds by academic field when conducting collective research projects. Second, in order to reinforce the collective research capability of Korea, the program to support students in masters and doctoral programs need to be expanded. These points should be reflected in the establishment of government R&D programs.

4.2.6 Need for a Global Network: This study analyzed the need to build a network by academic field in order to improve the effectiveness of the government policy on building global networks. The results of the analysis of interviews showed that there was a significant difference between sub-academic fields.

First, the field with the greatest need for a global network is the big sciences fields. The field of Experimental Particle Physics in which Professor Soo-Bong Kim studies is an area where independent research is almost impossible. The research team is generally composed on a global level, forming a super-scale research team composed of dozens of individuals to over a thousand individuals. Due to the size of the team, the organization itself is based on a pyramid structure that is usually maintained for more than 10 years. International awards are mostly awarded to the leader of the research team because of the enormous scale of the team. Masatoshi Koshiba (the leader of the research team to which Professor Kim belonged) was the only scientist to win the Nobel Prize in Physics from his team in 2002. Although there are some differences in the fields of Surface Physics or Low Temperature Physics (to which Professor Han-Woong Yeom and Professor Eun-Seong Kim are each members), global networks also play a considerable role in research activities.

The field of Chemistry that Professor Ryong Ryoo belongs to has a relatively lesser use of the global network compared to other fields. The research team (lab) is not that large, (composed of 5 – 20 individuals) and experiments do not depend on global networks. Although some differences exist among professors in Physiology or Medicine according to their interests and sub-academic fields, the formation of independent domestic teams is possible, similar to the field of Chemistry. Professor Zang-Hee Cho majors in a field that is closer to applied Physics rather than traditional Biology and has a greater need for a global network.

The government is currently pursuing the World Class University (WCU) project in order to reinforce the research capacity of domestic universities and strengthen networks with world-leading scientists. However, Professor Cho believes that the most effective way to boost domestic scientific capacity is to recruit prominent scientists full-time. Inviting noted leaders from the different science fields to Korea takes at least three years of long-term, continuous contact and persuasion. Korea needs to offer more enticing proposals and provide fixed settlement benefits for their families since they are already receiving satisfactory treatment and enjoying desirable lifestyles at home.

The above analysis illustrates the following policy implications: First, global research teams are commonly formed in the field of big sciences such as Particle Physics and the possibility for Korea to win a Nobel Prize in science could be relatively small. A future winner of a Nobel Prize must become preeminent in their field and supported by infrastructure with world-class facilities that are able accommodate and support global research teams. For example, the reason why Japan became a leader in Experimental Particle Physics is due to the ability to conduct continuous research based on local access to the highest quality of accelerators. In terms of the possibility of winning a Nobel Prize in science, the Chemistry field has more potential than Physics, and Physiology or Medicine (a rising new field) has more potential than Chemistry. Second, the relative need for a global network varies by the sub-academic field, which should become the basis of the government global network support policy. However, rather than implementing a standardized global network support policy regardless of academic field, it would be more effective if the government supported the domestic network or overseas programs according to the different fields.

4.2.7 Need for Research Eethics and Creative Research Culture: In order to generate world-class research results, the establishment of accepted scientific ethics and an innovative research culture that influence the research activities of creative scientists are of critical importance. In this light, the study reviews the status of Korean research ethics and examines future methods for improvement. According to the analysis of interviews, it is imperative to set up research ethics and establish a creative research culture in order for Korea to become an international leader in science.

First, interviewees commonly cite the sharing of research ethics as an essential factor for domestic scientists to develop into global-leading creative scientists. Research ethics influence the research activities of individual researchers, which ultimately lead them towards the desirable direction. Therefore, the level of awareness of research ethics shared by the scientific community determines the national level of science. In regions advanced in science (primarily North America and Europe), there is a broad awareness of research ethics in the scientific community. Therefore, any dishonest or unethical activities tend to be actively controlled or corrected by the scientific community prior to any investigations by society. The awareness level in Korea regarding research ethics is low in the scientific community as illustrated by the case of scientific dishonesty by Professor Woo-Suk Hwang in 2005. Therefore, it is highly encouraging that this is considered unacceptable and that more efforts are being devoted to this area.

Second, interviewees state that a stronger awareness of research ethics on a personal level, together with the cultivation of an organization or creative research culture in society are critical in the production of world-leading creative scientists. The culture of the organization or society surrounding the scientist can facilitate or impair the strengthening of awareness towards research ethics or motivation. Consequently, the international nurturing of prominent scientists by the scientific community requires the formation of a creative research culture on an organizational level (namely a university or government-funded research institute) and the movement to promote a creative culture on the social level.

The above interviews create the following policy implications: First, the government policy efforts to enhance the research ethics within the scientific community are the most important in reinforcing the basic science capability and producing world-leading scientists in Korea. The lack of research ethics awareness impairs the confidence of the government and society towards the scientific community and can result in a negative effect of impairing reliable and mid-long term support. Second, policy measures to promote a creative research culture within a research organization (such as a university or government-funded research institute) should be devised. Until now, the policy interest of universities and government-funded research institutes used to be mainly on hardware elements, such as overhauling governance. The future promotion of voluntary creative research activities by professors and researchers will require efforts to foster a creative research culture.

TABLE 3 Comparison of Academic Fields and Research Environments of Nine Korean Creative Scientists

Features of Academic field

PHYSICS					
Name	Sub-academic fields	Features	Name of major equipment (cost)	Early research expenses (including equipment)	Number. of co-authors in journals
Soo-Bong Kim	Experimental Particle Physics	-Big science -Individual research is almost impossible to conduct -Requires equipment costing up to hundreds of billions dollars -Dozens to hundreds of co-authors -Recording of co-author of journals based on alphabetical order (Position of 'first author is irrelevant) -Trend of research team leaders of winning Nobel Prize	Accelerator (few hundreds of billions of dollars)	$100,000	Some 30-500 individuals
Han-Woong Yeom	Surface Physics (Atomic ray)	-Atomic ray = an experiment highly sensitive to vibration (No vibration experiment needed) -New field that emerged only 10 years ago -As a basic academic field, it is expected to have enormous economic effect if connected with industry	Synchroton radiation Beamline (400 million dollars), Vibration-free laboratory (1million dollars)	Around $1,000,000	Around 5 individuals
Eun-Seong Kim	Low Temperature Physics	-A field which studies phenomena at a low temperature environment near the absolute temperature of 0 degrees -Experimental equipment is needed to create and maintain low temperature -Deletion of noise during experiment is important (independent vibration-free experiment necessary)	Vibration-free laboratory (1 million dollars)	Around $1,000,000	Around 5 individuals

CHEMISTRY					
Name	Sub-academic fields	Features	Name of major equipment (cost)	Early research expenses (including equipment)	Number. of co-authors in journals
Ryong Ryoo	Solid Chemistry	-A small number of joint researchers undertake focused experiments for a certain period (3-8 years) -Thesis written over 1-2 year period -Joint researchers are mostly post-docs rather than professors	Particle counter Synthesizer	$100,000	3-20 individuals
Su-Moon Park	Electroanalytical Chemistry (Conducting Polymer)	-A field that does not require a large amount of research funds -At this point in time, a laboratory can be built for 200-300 million dollars in start-up funding -No large-scale scientific facility required	FT-IR/FT-NMR (500 thousand dollars)	$200,000	Around 5 individuals
Hee-Cheul Choi	Solid Inorganic Chemical (charge transfer)	-Consumes around 3 years to create a thesis -Mainly collective research (small-sized joint research) -Joint researchers have interest in various fields -Short-term cooperation required during research in the conduct of tests and experiments	CVD, Clean room	$200,000	Around 5 individuals

PHYSIOLOGY OR MEDICINE					
Name	Sub-academic fields	Features	Name of major equipment (cost)	Early research expenses (including equipment)	Number. of co-authors in journals
Zang-Hee Cho	Nuclear Physics	-Production and performance improvement of equipment highly important -A systematic field and individual research is impossible -Interdisciplinary knowledge required (converged research)	7T NMR, PET	$250,000 ('75)	6-40 individuals
Kyu-Won Kim	Vascularization	-Numerous experiments and observation important -Collaboration between professor and graduate students important (Human resources are the most important) -A small number of joint researchers undertake focused experiments for a certain period (3-12) -Thesis written over 1-2 year period	Confocal Laser Scanning Biological Microscope	$10,000 (Around '90)	5-20 individuals
Eun-Joon Kim	Molecular Neurobiology (Neuroscience)	-Uses laboratory mice -Uses specially designed and nurture mice which are highly expensive (significant amount of materials	Laboratory mice (Around 100 thousand dollars per year)	$500,000	Around 10 individuals

Features of Research Environment

PHYSICS					
Name	Production of core accomplishments (time consumed)	No. of field changes	Major research funding source	Features and size of research team	Need for a global network
Soo-Bong Kim	7-10 years	None	SRC, Leading research	Corporate-style organization (Dozens to hundreds of individuals)	Need to permanently operate large research organization
Han-Woong Yeom	10 years	None	SRC, CRI	Fixed number of research team needed (Around 10 individuals)	Absolutely essential for creative ideas
Eun-Seong Kim	6 years	None	CRI	Fixed number of research team needed (Around 10 individuals)	Absolutely essential for creative ideas

CHEMISTRY					
Name	Production of core accomplishments (time consumed)	No. of field changes	Major research funding source	Features and size of research team	Need for a global network
Ryong Ryoo	7-10 years	39 years of age (once)	SRC, CRI, and National Scientist Award	Focused on small numbered teams (2 Post-docs+15 graduate students)	Case by case
Su-Moon Park	10 years	60 years of age (once)	SRC, US. DOE	Focused on small numbered team (Around 20 individuals)	Case by case
Hee-Cheul Choi	3 years	None	SRC	Focused on small numbered team (Around 10 individuals)	Small-sized joint research if needed

PHYSIOLOGY OR MEDICINE					
Name	Production of core accomplishments (time consumed)	No. of field changes	Major research funding source	Features and size of research team	Need for a global network
Zang-Hee Cho	10 years	Once upon appointment as Assistant Professor	UCLA, Government	Operation of an independent research institute (Around 40 individuals)	Collaboration with scientists of 3-4 advanced countries
Kyu-Won Kim	15 years	None	SRC, Oriented-based research, CRI	Led by doctoral program students (Around 15-20 individuals)	Collaboration with Japan, U.S., Canada
Eun-Joon Kim	Around 5 years	None	CRI	Experimental resources (mice) needed (Around 10 individuals)	Case by case

5. SUMMARY AND DISCUSSION

The Korean government is devising various policy tasks in order to produce world-leading scientists. However, most of the tasks are irrelevant and are impractical on why they should be undertaken or what kind of differentiation they have compared to policies for general scientists. This is because the theoretical grounds and on-site knowledge have not been fully incorporated into government policy tasks. Theoretical research and on-site studies must be conducted beforehand in order to install policies appropriate to creative scientists.

This study examined the influencing factors of creative scientists through theoretical contemplation and on-site interviews. This study identified personal and academic characteristics that influenced the research of a creative scientist and features of the government research environment to derive policy implications based on the Systems Model of Creativity.

The results of the study led to the following facts and policy implications: First, the size of joint research teams and recording method of co-authors of a journal vary by academic field. For example, the recording of co-authors in a significant number of journals (such as the Physical Review Letters) is based on alphabetical order instead of the level of contribution. This demonstrates that the government should consider the unique characteristics of journals when the evaluation of the achievements by scientists is based on journals.

Second, core accomplishments by domestic creative scientists were produced every seven to ten years. Until now, there was a lack of basic policies to support the emphasis put on the importance of reliable mid-long term support in the production of world-class creative accomplishments.

Third, creative scientists in Korea did not change research fields (or only changed them once) during their career. This implies that when the government provides research funding, it should enable scientists to research a certain theme continuously.

Fourth, the early research investment required by creative scientists was around 100 thousand to 1 million dollars in Physics, 100 thousand to 200 thousand dollars in Chemistry, and 10 thousand to 50 thousand dollars (excluding Nuclear Physics and Electronic Physics) in Physiology or Medicine. This provides the basis for the government to differentiate the size of seed research grants by different academic fields.

Fifth, most professors faced difficulties in acquiring research funding early on in their career, and the connection to research funding programs was essential.

Sixth, there is a considerable difference in the possibility of winning the Nobel Prize in science by academic field. In the field of big science (such as Experimental Particle Physics) global research teams and research leaders tend to win the Nobel prize, which means that there is a relatively low possibility for Korea to be the winner. Meanwhile, in the emerging fields of Physiology or Medicine, Korea has a relatively higher chance of winning the Nobel Prize in science as all countries have a similar start in the field.

Seventh, the need to support global networks for the production of creative scientists also differs by academic field. Such support was essential in the field of big sciences, whereas it was relatively less important in Chemistry and the fields of Physiology or Medicine that conducted laboratory research activities. This illustrates that the government must reflect such different academic features in its global network projects.

This study examined the characteristics of individual research activities, academic traits and the features of the government research environment as factors that influenced the research activities of creative scientists. Such research results are expected to be useful basic data in the establishment of policies for future world-class creative scientists.

This study was conducted based on interviews of nine male university professors and has limitations in fair representation and generalization. Nevertheless, five out of the nine interviewees are regarded as scientists that could be considered as candidates for the Nobel Prize in science. The other four scientists (although with somewhat less experience in research), have already been verified as having great potential and promise in research. It is necessary to interview a larger number of researchers in different fields, such as researchers in government-funded research institutes, corporate research centers, and female researchers, in order to enhance the generalization of the findings of this study.

The world is transforming from a knowledge-based economy to a creativity-based economy. The national competitiveness in the future will depend on the number of creative scientists and the formation of a creative research environment. Regardless of national development status, a continuous study of world-class creative scientists and diverse policies should be conducted for Korea to become a world-leader in science.

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