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International Collaboration in Multilayered Center-Periphery in the Globalization of Science and Technology

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This article analyzes international scientific collaboration in the context of the globalization of science and technology as a crossing point not only between local and global identities but also between scientific and sociocultural identities. It also elucidates how international collaboration—where middle scientific actors in the hierarchical multilayered center-periphery in the globalization of science and technology obtain advanced knowledge from core science and technology—takes place and structures the global division of research labor. This article emphasizes that we should develop the context of the globalization of science and technology with dynamic and interdependent interactions between multistructured, core-periphery scientific actors. Dichotomous colonialist discourse is not a useful analytical tool in this context. The author found that sociocultural factors, including economic, cultural, organizational, and political ones, as well as the multilayered center-periphery in the globalization of science and technology, operate as forces that encourage international collaboration.

Keywords: *international collaboration; international scientific collaboration between British and Koreans; reenactment of colonialist discourse; the multilayered center-periphery in the globalization of science and technology; ties between center and periphery in the scientific world system*

This article aims to investigate international collaboration in science and technology[1] in the context of inequitable international relations. Collaboration can be cross-disciplinary, cross-institutional, cross-geographical, and international. Cross-disciplinary collaboration involves inter- or multidisciplinary collaboration. Cross-institutional collaboration reflects collaboration between organizations, for example, academia-industry collaboration.

Cross-geographic collaboration is increasing between dispersed organizations as well as within organizations that have multi-site workplaces. Many studies (e.g., Glänzel, Schbert, and Czerwon 1999; Gómez, Fernández, and Sebastián 1999; Koutrakou 1995; Wagner and Leydesdorff 2003) also show an exponential increase in international collaboration. However, there are very few studies viewing international collaboration in the context of unequal international relations. Thus, this article has investigated international collaboration in the multilayered center-periphery in the globalization of science and technology as a conceptual framework, which provides a tool for analyzing international collaboration between unequal scientific relations. This article begins to discuss in some depth theoretical approaches that explain inequitable international relationships in science and technology. The article then presents an empirical research of what sociocultural backgrounds drive international collaboration between Korea (a scientifically less advanced country) and Britain (a scientifically advanced country). The empirical research focuses on the central question: "What internal motives and external imperatives are involved in international collaboration between Korean and British scientists and engineers?"

Theoretical Approaches

Academia-industry alliances are an increasing phenomenon on a global scale, and government policies actively foster these alliances by placing academia in the capitalization of knowledge.[2] Leydesdorff and Etzkowitz point out that innovation strategies based on the deliberate elaboration of academia-industry relations have been a universal phenomenon, in spite of different developmental histories and a broad spectrum of societies (1997, 155). Governments of every nation, along with universities and companies all over the world, actively engage in the development of science and technology to survive in the new environment of a knowledge-based economy. Hence, the use of science and technology for national, local, or organizational wealth creation is a universal phenomenon.

Collaboration and integration happen across national borders. The phenomenon of university-industry-government interactions has complex dynamic features of the overlay system, and this phenomenon tends to be formed to cope with knowledge-based economic development at a global level (Leydesdorff and Etzkowitz 1997). Etzkowitz and Leydesdorff contend that innovation processes take place across national boundaries, and nation-state innovation systems are being supplemented by regional and multinational innovation systems within the European Union and elsewhere (1997, 4). Thus, international collaboration and alliances have been establishing themselves. Gibbons et al. point out that manufacturing technologies are transferred to low-wage countries and that advanced industrial nations can only maintain their competitive advantage by using resources and skills that cannot easily be imitated (1994, 111). In addition, Gibbons et al. state that knowledge firms must keep their access to global intelligence and the new key techno-economic assets, because of the global dimensions of knowledge production. However, they also highlight some paradoxical consequences and novel contingencies of the significance and extent of the globalization of the economy stating that

> despite the emergence of a new intellectual division of labor in the wake of the widened capacity to use research and scientific knowledge produced elsewhere, the ability to engage in research and to utilize it remains highly unevenly distributed throughout the world. An actual increase of inequalities occurs also through the differentiating effects that globalization has on the actual ability to participate in the consumption of scientific knowledge, advanced technological products and systems, and leaves many regions and countries locked out completely" (1994, 113).

This raises issues related to international collaboration:

1. What does international collaboration mean in the global environment where there is an inequitable distribution of scientific competence?
2. What dynamics are involved in international collaboration in this situation?
3. Does this situation encourage international collaboration or not?
4. Are industrially newly developing or underdeveloped nations excluded from international collaboration?
5. Does international collaboration between organizations or nations with inequitable scientific competence take a distinctive form and exhibit unique characteristics?

Most research into collaboration has paid little attention to these questions. Gibbons et al. argue that the ability to transmit information cheaply and almost instantaneously throughout the world does not seem to lead to a more equitable distribution of scientific competence but rather to its concentration (1994, 113). Remarkably, marginal scientific actors' access to information does not necessarily mean that they can gain scientific competence. This may lead them to concentrate more on obtaining scientific information and applying it, instead of devoting themselves to knowledge production. Producing scientific information requires resources including material resources, experts, and symbolic properties, such as reputation and publications. Easy access to information cannot lead organizations and nations without proper resources to acquire scientific competence. Furthermore, application and development of scientific information requires tacit knowledge acquisition, which cannot be easily done with codified information. Thus, only organizations with research resources and scientific competence are able to produce knowledge and distribute it efficiently. This leads to a concentration rather than an equitable distribution of scientific competence.

International collaboration is driven by the market need to be internationally competitive. This readily occurs when compatible organizations and nations combine each party's expertise and technical skills, as well as equipment and accumulated data. However, there is another level of international collaboration derived from the inequitable global environment of research resource concentration and scientific competence distribution. What dynamics are involved in this level of international collaboration? In addition, what form does this level of international collaboration take, and what characteristics does it exhibit? To understand these issues, I will use the reenactment of core-periphery relations in science and technology, and ties between center and periphery in the scientific world system, as theoretical frameworks. Then, I will also discuss dynamics of scientific collaboration in general, which will be basis of understanding and comparing dynamics involved in international collaboration of an empirical study in this article.

The Reenactment of Colonialist Discourse and Ties between Center and Periphery in the Scientific World System

The reenactment of colonialist discourse provides an understanding of the hierarchical structure of international relations in science and technology. The implication of this reenactment is that core-periphery relationships have shaped scientific practices and scientific actors' identities; the means of reenactment have not been direct violence and political force but the interactions between scientific actors and communities self-referential systems, infrastructures, reputations, recognition, nationalities, political and scientific heritage, and so forth.

The reenactment of colonialist discourse contains the fundamental notion that sociocultural elements, such as nationality, scientific heritage, and infrastructures,[3] predetermine the status of an individual scientist and engineer, or an individual institution that stands in the core or periphery in the hierarchical structure of international relations (Hwang 2005; Schott 1998; Traweek

1988, 1992). Traweek states that there exists a stable ranking of institutions in particle physics, internationally, and that all the major and eminent laboratories for particle physics in the world are located in North America and Europe (1988, 109). This is well documented for big science, such as particle physics, and it seems likely that this holds for other areas of science as well. Zaltman (1968, cited in Crane 1972)[4] and Crane (1972)[5] mention that international scientific community networks have been dominated by the United States and the European countries. Rothboeck is also not optimistic about whether the workings of the Information and Communication Technologies (ICT) industry enable some latecomers to move into the group of pace-setting countries and argues that empirical evidence shows that the ICT industry seems to maintain the divisions between the core and the periphery (2000, 55).

There is a structure of scientific knowledge creation and consumption based on a core-periphery relationship in the scientific world system. Hwang states,

> Peripheral science consumes scientific knowledge produced by core scientific actors and becomes a routine application. Scientists and engineers in the periphery consume this knowledge. Then scientists and engineers in the periphery produce subsidiary knowledge and implementation technologies in the course of applying knowledge to end products and scientific activities. The subsidiary knowledge and technologies then become marketable commodities. Compared to this, core science and technology become a Mecca of advanced scientific knowledge production and create a labor division in scientific knowledge production. When scientific knowledge leads and links to a chain of bodies of knowledge and the chain is eventually used for producing the end products and implementation technologies, scientific knowledge is shaped in a hierarchical branch structure. (2005, 392-93)

Arrow (1962)[6] argues that knowledge is not simply the end product of inventive activity but also a major input into the process of new knowledge creation (cited in Cameron and Le Bas 1999, 241). Periphery scientific endeavor is reliant on the provision of this knowledge, which it consumes but does not produce itself: its output—technological application—is seen as being inferior, even parasitical. Where a country seen as peripheral is, in fact, producing some core knowledge, that activity may be prejudged in the light of this assumed lower status.

Sociocognitive perverse effects (Cerroni 2003) or the Matthew effect (Merton 1973) in scientific reputation affect the processes of approving knowledge in the scientific community. This applies not only to individual scientific actors but also to geopolitical groupings such as nations and regions. To a great extent, scientific actors from the periphery are disadvantaged by their knowledge claims being approved by the international scientific community through the self-referential system. It is only in the last couple of decades ago that Southeast Asian scientists have begun to be accepted without prejudice by Western scientists (Traweek 1992).

Schott (1998), following Ben-David (1971), explains international collaboration by ties between center and periphery in the scientific world system. He argues that the center attracts students from around the world and attracts deference from scientists throughout the world. He emphasizes that in the global networks of ties of deference, influence, emulation, and desire of recognition, there is an accumulation in the center of ties. This manifests in the center as an enhanced self-reliance and centrality, while the globalization of the scientific community is crystallized into the reenactment of hierarchical center-periphery formation (Schott 1998). He states that during the twentieth century, the region that attracted most deference and became most central in the network of deference is evidently North America, and the second-most central region in this network is Western Europe, while other regions are peripheral.

The network of deference is a particularly important concept for international collaboration in that scientific actors from the periphery try to have connection with the center in various collaborative ways, such as sojourning for education (Martin-Rovet 1995) and training, knowledge transfer, and informal networks. This connection between center and periphery in the view of scientific actors from the periphery is closely related to their recognition, reward, emulation, and competence as scientific actors at both global and local levels. Schott states, “In peripheries of the world of learning, a sojourn to the center is a credential in itself, enhancing prestige of the sojourner, and in some peripheral countries it is even somewhat necessary and sufficient condition for certain appointments” (1998, 123). Collaboration between supervisors and research students, and formal and informal collaboration and close relationships between them after students’ education, are not new phenomena (Crane 1972), and this applies to educational sojourners from periphery to center (Hwang 2005; Schott 1998). Thus, sojourners from periphery to center promote international collaboration.

However, the theoretical concept of colonialist discourse is too dichotomous to apply to the multilayered structure of the real world (Hwang 2005), and this suggests a problem with the center-periphery notion: there is a middle or gray area that belongs to neither the center nor the periphery. Hwang says,

> Korea is ostensibly independent and nearer to core science in some fields, as a result of selling technologies worldwide, and she has been recognized as one of the leaders at producing some technical knowledge and implementation technologies for end products. In this sense, Korean science and technology can be described as core. However, the Korean interviewees predominantly claim that they are not engaged in core knowledge production but instead are involved in the consumption and adaptation of core knowledge to local practices. This applies to most fields, even to those in which Korea is a leader. Korean basic science and research are, therefore, necessarily dependent on core science. In this sense, Korea belongs to the periphery in the calibrated structure of scientific knowledge production. Thus, the dichotomy of the theoretical concept of core and periphery is too simple to explain the multilayered structure of scientific knowledge creation and international scientific activities. (2005, 418-19)

Gibbons et al. (1994) also support this view of a multilayered structure as they state that competitiveness and globalization form a multifaceted structure of scientific knowledge production and organization, and the emergence of a new international division of intellectual labor is a consequence of the fact that many more countries and firms have acquired the capacity to use research and scientific knowledge produced elsewhere. They recognize that, as with production, scientific research undergoes constant shifts in international competitiveness, with new countries entering and old dominance patterns breaking up. Wagner and Leydesdorff (2003) analyze international coauthorships between 1990 and 2000 and conclude that the center-periphery model of international scientific collaboration (e.g., Ben-David 1971; Schott 1998) can be replaced with a model that accounts for various centers that both collaborate among, and compete with, one another for human resources from smaller national systems.

The middle or gray area has developed in the process of globalization of science and technology. Homogeneous intellectual character, scientific activities, and scientific research problems at a global level are formed in the process of the transmission of core science to science in the periphery (Forbes 1987; Hess 1995) and do not serve people and society in the peripheral nations. In examples such as the inadequacies of an agricultural model of scientific work transferred from the Rockefeller Foundation to the local conditions of rural families whose farms were small and labor-intensive in Mexico (Cueto 1994), the problems resulting from this homogenization have been well documented (Gibbons et al. 1994; Hwang 2005; Pyenson 1989; Vessuri 1987). Core science has a continuing heritage of basic research as its foundation, while peripheral science has lost its heritage of knowledge production and so is dependent on core science to provide knowledge for its consumption: this creates an imbalance, with the periphery unable to sustain its science and technology independent of the core.

Even Japan, which shows Western science and technology successfully transferred to a country that had not first been Westernized (Fuller 1997) and has been recognized for her strength in technological development, seems to display this unbalanced structure. Sigurdson suggests, "Strengthening basic research is becoming an increasingly important lever for continued industrial and technological advances in a flexible global economy. Thus, Japan must strengthen the foundation of basic research that will place it amongst the world leaders in technology development, and use this edge to help to raise the world's technological level by accumulating technology-related data" (1995, 327).[7] Gibbons et al. (1994) also argue the importance of a balance between basic research and technology for markets for a country's scientific independence, in terms of scientific research and products.[8]

The imbalance between the two seems to fortify the colonization of intellectual property. Gibbons et al. highlight the fact that "scientific funding mechanisms are still national, and scientists' career paths are still overwhelmingly shaped within the context of individual countries, while science is international" (1994, 129). With this notion granted, the responsibility regarding the capacity for the production of scientists and scientific knowledge initially belongs to an individual nation. When countries are unbalanced with regard to the basic research and applied or implementation technologies, a situation develops where the countries are extremely successful in the commodification of the outcomes of scientific activities.

Although some countries, such as these East Asian countries, are becoming known as being technologically advanced and center-status (Glänzel 2001; Schott 1998) and are included in the network of knowledge access mainly in the semiconductor industry (Rothboeck 2000), they may not have fully integrated science and technology and still cannot function independent of the "traditional" center, despite their production of some core knowledge. In this sense, we can identify a middle or gray area that does not fit into the binary opposition of core-periphery, suggesting the need for an alternative model. Notably, though, middle science is made out to be a persistent parasite on core science for knowledge and information in the same way as those countries more easily allied to the periphery; this detracts from recognition of their burgeoning core status, perpetuating the imbalance between core science and implementation technology.

Thus, we should recognize that the globalization of science and technology can be a more appropriate theoretical approach than the dichotomous center-periphery relationship for this study. However, it should be emphasized that the globalization of science and technology is not based on the equal expansion of science and technology at a global scale. This means that globalization implies the geopolitical inequality of scientific distribution, accumulation, and reputation and that multilayered center-periphery relationships exist. Hence, I refer to this phenomenon as multilayered center-periphery relationships in the globalization of science and technology.

The Dynamics of Collaboration

As this article discusses the dynamics involved in international collaboration, it might be useful to briefly categorize the dynamics of general collaboration. I categorize the dynamics as the scientific content, scientists' networks, and social contexts. These three categories provide a general understanding of what drives collaboration.

Scientific Content

Interdisciplinary content and the sharing of instruments are prototypes of the category of scientific content. As some research problems cannot be solved by the existing theoretical concepts or methods of a single discipline of science, they are pursued within the scope of multiple disciplines. Bordons et al. (1999) point out that interdisciplinarity is now considered to be essential for the advancement of science. Multidisciplinary collaboration is a mode of producing integrated knowledge from different areas. Sophistication of equipment and sharing rare and expensive instruments, especially in big science (Galison and Helvy 1992), such as high-energy physics and astronomy, inevitably require collaboration. Thus, interdisciplinary application and manipulating and building equipment are the main determinants of collaboration in the category of the scientific content.

Scientists' Networks

The second category, scientists' networks, explains what compels scientific actors to collaborate, without considering the scientific content per se. This category includes insecurity in highly competitive environments, uncertainty of scientific findings, social networks of collaborators (e.g., previous supervisor, previous research team members, core set in controversies [Collins 1974]), and career seeking. One important factor in this category is the social interaction between actors in terms of the growth of scientific knowledge. Crane (1972) argues that a few highly productive scientists set priorities for research and recruit and train students who become their collaborators. They maintain informal contact with other members of the scientific area in stage 2 of the series of stages through which the growth of numbers of new publications is passing.[9] This indicates not only that scientists set up social interactions for active knowledge production but also that collaboration is one of these social interactions.

In addition, scientists use formal and informal contact with other scientists to obtain information on other scientists' research for their knowledge production. Collaboration is a salient source of scientists' social contact because it provides intensive communication, which can offer scientists research ideas and information on similar research. Thus, scientists predominantly need to participate in social networks for obtaining information. Collaboration is one of the ways that scientific actors are involved in social networks.

Social Contexts

The last category is related to extraneous factors inextricably linked with scientific content and scientists' networks. This category pertains to contextual changes including social changes, which bring about the proliferation of collaboration. For example, Mackenzie and Jones (1985, 1) ally new opportunities for collaboration in U.K. universities and former polytechnics to the government's cuts in higher education funding at the beginning of the 1980s.

Scientific capacity including international reputation and recognition (Ben-David 1971), political and policy promotion including governments' fostering of international collaboration (Wagner et al. 2001), historical factors including geographic proximity and colonial relationships (Zitt, Bassecoulard, and Okubo 2000), and globalization of science and technology (Gibbons et al. 1994; Wagner and Leydesdorff 2003) are all social context factors influencing general collaboration as well as international collaboration.

Social contexts provide a strong impetus to make actors change their view of scientific knowledge and to make them accept collaboration as the norm. In this respect, collaboration is no longer an actor's choice but instead has come to characterize scientific enquiry. While the interdisciplinary nature of scientific content forces scientific actors to conform their attitude toward collaboration in organizational contexts, this category compels the scientific community as a whole to change its attitude toward collaboration. The prototypical maxim, "under the banner of bolstering international competitiveness by collaboration between academia and industry" (Mackenzie and Jones 1985), can be a matter of ideology, which represents the scientific community's conformation with social and political promotion of collaboration. This change of the scientific community's attitude toward collaboration is conducive to the consequential institutionalization of collaboration.

Katz and Martin's (1997) literature review on factors contributing to collaboration name ten common factors to account for the increase of coauthorships: (1) changing patterns or levels of funding; (2) the desire of researchers to increase their scientific popularity, visibility, and recognition; (3) escalating demands for the rationalization of scientific manpower; (4) the requirements of ever more complex instruments; (5) increasing specialization in science; (6) the advancement of scientific disciplines; (7) the growing professionalization of science; (8) the need to gain experience or to train apprentice researchers; (9) the increasing desire to obtain cross-fertilization across disciplines; and (10) the need to work in close physical proximity with others to benefit from their skills and tacit knowledge (Katz and Martin 1997, 4). The dynamics of collaboration from Katz and Martin's (1997) literature review show three prominent factors: funding (social contexts), scientific actors' networks, and interdisciplinary (scientific content), which can be recategorized as the three categories suggested in this article.

In the sociology of scientific knowledge, however, the demarcation of categories in the dynamics of collaboration may be inexpedient, because the scientific content, scientists' networks, and contexts cannot be separated in a single scientific practice. However, I regard social contexts as the most fundamental driving force of collaboration. Seidel (1992) points out that big science in California arose to cope with the problems of power production and distribution, as well as the cultural fascination of Americans in general with large size. This includes the goal of building ever-larger scientific facilities.[10] With respect to social influences on changes in science, Star asks, "Can there be a revolutionary science/technology in the absence of revolutionary social change in other spheres?' (1995, 8). She answers the question by saying, "to the extent that one believes in the interpretation of spheres and science as a social institution of its historical time and place, the answer must be no" (1995, 8).

Collaboration is closely related to the social changes that result in new modes of knowledge production and in the privatization and commercialization of scientific knowledge. This being true, Star's (1995) proposition can be applied generally to the relationship between collaboration and social contexts. In other words, collaboration is predominantly derived from social contexts.

Literature shows that the three categories can be applied to the dynamics of international collaboration. Wagner and Leydesdorff (2003) provide literature review on the rise of international collaboration and suggest two broad categories: factors internal to science (center-periphery theory, internal disciplinary differentiation, and the financial demands of big science) and factors external to science (increased public and policy support for research and development, historical relationships, colonial ties, and geographic proximity, and the enhancement of communication technologies including the Internet). External factors are obviously included in the category of social contexts, and internal factors in the scientific content suggested in this article. I think center-periphery theory can be included in both the scientists' networks and social contexts categories of this article, because center-periphery is an arena of the scientific community as well as geopolitical and historical factors.

The categorization of the dynamics of collaboration is designed to help easier understanding of what drives collaboration and becomes the basis of the comparison of dynamics of international collaboration between Korean and British scientific actors in the empirical research in this article. This article will investigate what dynamics in which categories will most encourage international collaboration in the views of Korean and British scientific actors and compare the factors contributing to their international collaboration.

As research into international collaborations has been focused on the quantitative exponential increase of international collaboration by using coauthorships (Glänzel 2001; Persson, Glänzel, and Danell 2004; Wagner and Leydesdorff 2003), any qualitative studies on the dynamics of international collaboration, let alone those on the dynamics of international collaboration in the context of unequal international relations, have been extremely rare. For real-world investigation, I examined the dynamics involved in international collaboration between Korean (middle or gray area) and British (center) scientists and engineers with the perspective of the multilayered center-periphery in the globalization of science and technology.

Research Method

Research Question

The central research question is as follows: "What dynamics are involved in international collaboration between scientifically advanced and less advanced countries?" This question focuses on why parties who do not share scientific status and recognition participate in international collaboration. For this question, I conducted two sets of research. The one is about external imperatives and internal motivations that drive international collaboration from individual organizations' standpoint. I asked ten Korean scientists and engineers why they participate in international collaboration (table 1). In addition, I asked eight British scientists and engineers the same questions (table 2). I asked Korean interviewees specifically questions as follows:

Table 1
Information on Interviewees—Work Experience and Present Status in the United Kingdom

	Field	Work Experience	Present Status in the UK
K1	Mechanical engineering	Senior research engineer (6 years) at Daewoo Motor Company	PhD student in mechanical engineering at Imperial College
K2	Biochemistry	Postdoctorate researcher at the Institute of Food Research (18 months)	Postdoctorate researcher at the Institute of Food Research
K3	Electrical engineering	Safety analyst and inspector at the Korean Institute of Nuclear Power Plant (12 years)	Just finishing PhD at Imperial College
K4	Civil engineering	Environmental safety researcher at the Research Institute of Science and Technology (RIST) in Korea (5 years and 6 months)	PhD student in civil engineering at Imperial College
K5	Mechanical engineering	Electric power generation researcher at the National laboratory	PhD student in mechanical engineering at Imperial College
K6	Food science and technology	Food safety analyst in Korean Food and Drug Safety Supervisory Office (14 months)	PhD student in food science and technology at the University of Reading
K7	Environmental engineering	Research assistant at the University of Seoul (4 years) Research Intern in Chang—An Environment Consultant Inc. in Korea (6 months)	PhD student in construction engineering at the University of Reading
K8	Physics	Research engineer at Daehan Company (5 Years), research engineer at Donghee Company (2 years), and visiting scientist at Korean Research Institute of Standard Science (2 years)	PhD student in physics at Imperial College
K9	Meteorology	Researcher at the Meteorological Research Institute in the Meteorology Office of the Korean government (12 years), director of Marine Meteorology Research Laboratory	PhD student in meteorology at the University of Reading
K10	Food science and technology	Food technologist at the Korean Agricultural Chemistry Laboratory in Fiji Government Research Station (3 years) Visiting Researcher at the Cellular & Molecular Biology Laboratory in Queen Mary's & Westfield College (3 months)	Postdoctorate researcher in structural biology at the Institute of Cancer Research (ICR)

Table 2
Information on Interviewees—Position and Roles

	Position	Roles
UK1	Professor of Ceramic Materials in the Department of Materials, Director of Centre for Tissue Regeneration and Repair Associate director of Interdisciplinary Research Centre (IRC) in Biomedical Materials	Managing his own laboratory, setting up international collaborative relations, running technology transfer companies founded by his laboratory, and managing research resources and projects
UK2	Professor of experimental aerodynamics in the Department of Aeronautics, Profile of Deputy Rector, and Pro Rector of Projects	Having strategic and management responsibilities for academic leadership, planning, finances, and managing staff and student matters across faculties. Facilitating cross-faculty communication and leadership at the college level. Being involved in serving as the college client for major new undertakings
UK3	Technology marketing manager in the Centre for Process System Engineering	Organizing relations with industry, obtaining funding from industry and transferring technology to industry Note: Dr. Colclough worked in industry for 20 years. The Centre for Process Systems Engineering carries out research into techniques for an integrated approach to all aspects of design, operation, control, and the planning and logistics of distribution for the process industries.[a]
UK4	Lecturer in chemical engineering	Running projects, obtaining and managing research resources, project performance, supervising PhD students and postdoctoral researchers, and teaching undergraduate and graduate students
UK5	Lecturer in chemical engineering	Same as above
UK6	Director of Centre for Environmental Control and Waste Management Lecturer in microbiology	Same as above
UK7	Head of fuel cell and hydrogen research in the Centre for Energy Policy and Technology Research associate in energy-environment policy in the Centre for Energy Policy and Technology	Same as above

a. This is from the promotional material of the Centre for Process Systems Engineering.

Table 3
Information on Interviewees—Status in Korea and the United Kingdom

	Status in Korea	Status in the Laboratory in the UK	Research Rield and Project
K11	Assistant professor	Postdoc research fellow, from the Cancer and Immunogenetics Laboratory, Weatherall Institute of Molecular Medicine, Oxford	Researching into the gene that generates cancer of the intestine
K12	Assistant professor	Postdoc research fellow in the Islet Physiology and Ion Channel group, University Laboratory of Physiology, at the University of Oxford	Conducting experiments of the different functions of Ion (K_{ATP}) channels in the pancreas that secrete insulin, the heart, and in blood vessels
K13	No work experience	Research fellow in the Department of Ship Science at the University of Southampton	Researching into joint technique for ship building and designing curved-shaped panels for ships
K14	No work experience	Postdoc researcher in the School of Ocean and Earth Science at the University of Southampton	Researching into fish breeding with gene transformation; biotechnology based in molecular genetics
K15	Work experience as postdoc researcher for about five years	Postdoc researcher at the laboratory of the Weatherall Institute of Molecular Medicine, Oxford	Cloning a particular human gene and cell line expression

1. What is the scientific status of Korea in the hierarchical structure of international relations in science and technology?
2. What drives Korean interviewees to study abroad or get a position doing work experience in the United Kingdom?
3. Why do Korean collaborators conduct international collaboration?

For British interviewees, I asked what drives international collaboration generally and why interviewees participate in international collaboration.

The other set of research is about the dynamics of international collaboration from individual partners' standpoint of ongoing international collaboration between the British and Korean scientists and engineers. I asked ten Korean scientists and engineers (tables 3-4), six British and two European ones (one German and one Dutch, tables 5-6), and one South African with British nationality why they participate in international collaboration.

Table 4
Information on Interviewees—Status, Roles, and Field and Organization

	Status	Roles	Field and Organization
K16	Group leader	Research management, collaboration management	LCD (the liquid crystal display), Company
K17	Project leader	Stimulating collaborative projects, supporting communication with the U.K. and Dutch collaborators and creating a Web page for activating communication between collaborators	LCD, Company
K18	Project leader	Initiating experiments conducting projects and communicating with the U.K. and Dutch partners	LCD, Company
K19	Senior researcher	Initiating experiments, conducting projects, and communicating with the U.K. and Dutch partners	LCD, Company
K20	Researcher (the Korean exchanging person)	Initiating experiments, conducting projects and communicating with the Korean partners	LCD, Company

In this set of research, I examined two ongoing collaboration cases. As investigating one ongoing collaboration between Korean and British laboratories (table 4 and table 6), which is already set up, I asked interviewees in this collaboration what the nature of their ongoing collaboration is, and the results and expected outcomes of collaboration instead directly asked them what dynamics are involved in each laboratory. Questioning the dynamics of collaboration can be too broad for interviewees to answer directly related to this collaboration. Accordingly, I asked what the nature of their collaboration is and what the results and expected outcomes of this collaboration are, and inferred the dynamics from them by combining this knowledge with the backgrounds of collaboration.

The other ongoing collaboration case is about collaborations taking place in the British laboratories where Korean scientists and engineers participate as researchers (table 3 and table 5). For this case, I asked what drives Korean interviewees to study abroad or get a position doing work in the United Kingdom, and whether their educational or work sojourn is related to the scientific status of Korea in the hierarchical structure of international relations

Table 5
Information on Interviewees—Status and Research Field and Project

	Status	Research Field and Project
South African 1	Postdoc researcher, Cancer and Immunogenetics Laboratory, Weatherall Institute of Molecular Medicine, Oxford	Researching into the genetic pathway leading to colorectal cancer and transfixion or introduction of mutated forms of genes into colorectal cell lungs to look for function or the evidence of function
German 1	Senior researcher in the pancreas, which secretes insulin, in the heart and blood vessels	Finding out about influential cells of diabetes and looking at the pancreatic beta-cell, with molecular and electrophysiology techniques and investigating how their structure changes the function of the protein
UK8	Professor of adaptive systems, at the Institute of Sound and Vibration Research, at the University of Southampton	Research into the connections between the physical world and digital signal processing. Originally in relation to the modeling and synthesis of speech and, more recently, in relation to the active control of sound and vibration and biomedical signal processing and control, particularly the early detection of epileptic seizures from electroencephalogram signals and the control of functional electrical stimulation (FES) cycling
UK9	Dean of the Faculty of Engineering and professor of signal analysis at the Institute of Sound and Vibration Research, at the University of Southampton	Applied digital signal processing and theory and application of time series analysis, with particular reference to problems in acoustics and dynamics. Currently supervising doctoral students studying blind inversion and time-frequency methods

in science and technology. For British and other-nationality interviewees, I asked what drives international collaboration generally, why interviewees participate in international collaboration, and what the nature of their current collaboration is.

Interview as a Research Method

To obtain data, I administrated interviews as my main research method. I do not share the positivist's belief that the interview is a mirror reflection of social reality, and my perspective of the interview is closer to the interactionist

Table 6
Information on Interviewees—Status, Roles, and Field and Organization

	Status	Roles	Field and Organization
UK10	Group leader	Research management, collaboration management	LCD (the liquid crystal display), and physics, Company
UK11	Deputy leader	Assisting the group leader, initiating experiments, conducting projects, and communicating with the Korean partners	LCD and physics, Company
UK12	Project leader	Initiating experiments, conducting projects, and communicating with the Korean partners	LCD and physics, Company
UK13	Project leader	Initiating experiments, conducting projects and communicating with the Korean partners	LCD and physics, Company
Dutch1	Project leader (the Dutch exchanging person)	Initiating experiments, conducting projects, and communicating with the U.K. and Dutch partners	LCD and physics, Company

tradition. Miller and Glassner say that the interactionist tradition embraces the view that interview participants construct not just narratives but also social worlds through the meanings they attribute to their experiences and social worlds (1997, 100). I would like to make two points relating to the discussions of the interview as a research method that contains similar notions as those mentioned by Miller and Glassner (1997): one is that interviewing is a tool for obtaining the systemic knowledge of social worlds. This, importantly, includes how interviewees project themselves within their stories of experiences in social worlds through their beliefs, perceptions, attitudes, and emotions reconstructed in their stories.

In addition, I believe that sociology deals not with a neutral or natural obdurate reality out there but with the interviewees' incessant constructions and reconstructions of social worlds that cannot be isolated from them. The other is that the disposition of interviewing pertains to interactions between participants. Interviewing is not just digging out neutral and natural information that sheds light on social worlds but carrying out systematic sense-making processes that produce sociological knowledge. However, I believe that the view of interaction must not discount the interview as a method for obtaining information on the social world, as Miller and Glassner maintain that "interviews have the capacity to be interactional contexts within which social worlds come to be better understood" (1997, 109).

I wanted to tackle the background motivations of international collaboration, which means that what sociocultural aspects compel international collaboration should be explored. This issue includes research participants' perception of socicultural backgrounds as well as collective and individual evaluation of their scientific status. This contains a practical implication of research method selection, and I consider that in-depth interviews would be a pertinent research method.

All interviews were tape-recorded and transcribed. As Korean interviewees did not want to use English for interviews, all Korean interviews are exclusively in Korean. This causes some difficulties in transcribing interview data. I had to translate Korean interview data into English for English transcriptions. The most important implication of this translation matter is that content analysis is technically impossible without specialized tools. Deutscher discusses communication problems derived from linguistic differentiation ("the nuances of language and social research," 1977, 244) even within a monoliguistic situation and a given constant cultural context in interviewing. He mentions that "his previous research shows that even the dichotomy between a negative response and an affirmative response is not easily translatable in different languages" (1977, 243-44) and contains cultural diversity.

When understanding a meaning through a particular word in cross-languages is involved in research, methodological implication may become serious. This becomes greater when cross-linguistic research aims at achieving comparative analysis with content analysis. Accordingly, the content analysis, qualifying degrees of interviewees' emotions or reliability by quantifying the frequency of the use of a certain word in interview data, is not considered in analyzing the collected data here. In translating Korean interview data, what I have done is to summarize the meanings of what the interviewees said as much as possible. It is extremely difficult even for a trained translator to convey exactly the depth of emotion and the various degrees of expressions. Thus, I believe that content analysis is not an adequate method for cross-linguistic data analysis. I have constructed understandings of international collaboration as theoretical backgrounds to my empirical study, and from this, I pursued thematic topics that were investigated in interviews. In this case, the data analysis is a way of understanding social situations and finding out how interviewees' reports correspond to my theoretical frameworks.

Results

The analysis of international collaboration focuses on what sociocultural imperatives are operating in international collaboration in the context of inequitable international relations. I have investigated why Korean and British scientists and engineers collaborate when they do not share common scientific statuses and recognition.

Sociocultural Aspects of International Collaboration

This study found that a focus on scientific content in collaboration, based on expertise exchange for knowledge creation, cannot explain some important problems of international collaboration. Three points from my interview data highlight the sociocultural aspects of collaboration.

First, international collaboration, between scientifically advanced research organizations and less advanced ones, clearly shows research labor division at a global scale. An ongoing collaboration between the Korean laboratory and the laboratories in the multinational company is classified as a complementary collaboration. The U.K. research laboratory group has strength in the understanding of the basic physics of operation and has a profound theoretical knowledge in the field. The Korean laboratory has advanced technical skills in implementation and scaling up. The European collaborators can evaluate their theories for production with the cooperation of Korean collaborators. The proof of their technical theories is important in industry, if they are to be useful for application in end products for obtaining patents and licenses. In the immediate term, they earn funding from the Korean laboratory. In addition, from the point of view of the Korean laboratory, the Korean collaborators can obtain advanced technology, which they cannot produce with their limited manpower and short-term research scheme. Thus, this is very much a complementary form of collaboration.

The complementary collaboration shows that the relations, between the two research organizations, have several aspects. First, they demonstrate how the imbalance of basic research and technology implementation, in non-Western and newly developing countries, shapes the basic relationship between the two organizations. The fundamental structure of this collaboration takes the form of the research division of basic science and its implementation. Second, they are stretched beyond the expectation of the unilateral technology transfer, from core to periphery. The relations between the two research organizations explain the limitation of the theoretical concept of discourse on core and periphery, in the daily production of scientists and scientific knowledge that is applied to the multilayered structure of the real world.

Core-periphery in science and technology is too dichotomous to apply to the multilayered structure of the real world. The complexity of international relations in global technoscience does not apply a unilateral and integrated way of technological influence from core to periphery. However, it includes various layers and multifaceted forms of relationships and influences the core-periphery relationship. In particular, some middle-positioned countries in the core-periphery relationships, including some newly developing East Asian countries, continuously have technical influences on core countries' research directions and interest foci. Furthermore, they tend to commission advanced countries to compensate for their lack of profound theoretical basis in technology. Consequently, the technical influences and initiatives are multilateral between advanced and newly developing countries, and a system of research division has been established between them.

However, despite this complementary benefit of this collaboration, Korean collaborators feel inferiority and submissiveness. A Korean international collaboration coordinator reports this aspect:

> Both parties should have individual and independent technical capability and strength. We believe we have them, as well. Then, the relationship has collaborative meaning. Ideally, producing each party's own technology should go along with producing collaborative technology. But people might suffer confusion, in thinking they can just take the collaborators' advanced technology, and not need to make any effort. We have this problem internally. From the executives' point of view, high ranked managers can say we can just research applied technology, because the collaborators of the multinational company have strength in basic research. But, this does not make any sense. The originality of advanced technology comes from basic research. So, we cannot obtain patents without this originality. Without individual and independent research into both basic and applied science and technology, we cannot fulfill the real meaning of a partner, and we can only just be a transferee and technology evaluator, and this means we become a laboratory without research. I don't think the division of basic and applied technology makes any sense. Our researchers are worrying we will be subordinate to them. We always have to learn technical skills from them, and therefore we will be researchers without doing research. Or some may think managers force us to collaborate with the UK and Dutch collaborators, despite the fact that they are not that much better than us.

This is a good example of scientists and engineers in developing countries being concerned that they may become peripheral scientific actors, within the unequal international relationships, in science and technology. The Korean collaborators' concerns are contradictory to the management level's perspective. This implies that the management level already places the Korean laboratory in the complementary structure of the division of research. However, the Korean researchers resist their positions as peripheral scientific actors. They believe their level of scientific competence is equal, or even superior, to that of their collaborators.

Second, international collaboration does not necessarily produce scientific knowledge but instead the exchange of resources. One British interviewee provides an example, referring to an occasion where he obtained funding from a major Japanese company: "They are funding manpower, and they pay for all sorts of travel, some consumable things, any software you need for the project. They are quite generous in terms of the project." Even multinational brand images can be achieved through international collaboration. A British technology marketing manager identifies this, saying, "In association with Imperial College, scientists publish together and the fact that they are funding research are all very strong points for the Japanese company. It shows that they are a multinational company and that they are supporting research in a world-class institution. It's very good for them and good for their image."

Last, international collaboration takes place to obtain recognition for scientific activities and to obtain research resources. This is another aspect of international collaboration. One British interviewee highlights this aspect by saying, "Actually, a lot of work I have done until very recently hasn't much interest in the UK. So, I have to collaborate with external people because they are the only people interested in it. It has been driven by necessity for me. Until 6 months ago, it was very difficult to get funding in the UK." This is an excellent example of scientific actors seeking recognition of their scientific activities and research resources through international collaboration.

Because of unequal international status in the scientific enterprise, scientists and engineers who have received less recognition for their research activities internationally and work in poor research environments (peripheral scientists and engineers) tend to seek research experience in internationally recognizable research organizations (core science and technology laboratories). This is encouraged and supported by individual research organizations in scientifically less-advanced countries and by governments from underdeveloped and newly developing nations (peripheral science and technology). Peripheral research organizations and governments provide funding for their scientists and engineers to encourage them to acquire research experience in core science and technology. International collaboration therefore provides twofold opportunities:

1. From the standpoint of peripheral scientists and engineers, they can learn how "core science and technology" works and play an intermediary role in importing advanced knowledge to their countries. In addition, they have an opportunity to develop a high-profile career when they return to their countries.

One Korean interviewee spells this out and says, "First, I could have work experience in the most advanced lab in the world. My first purpose to come here was to find out how they have achieved the most advanced lab in the world, by observing how they work and what equipment they use. Additionally, I think my field in Korea can be improved, by networking people here. I want to conduct experiments with people here and work in a different research environment."

2. From the point of view of internationally recognizable organizations, they form international connections that allow them to promote and transfer their advanced knowledge. Furthermore, they can use highly motivated and talented manpower from the periphery, as lower-level research manpower. My work suggests that the latter is the primary determinant.

For example, one British interviewee says,

> As I said, again, this is a world center for acoustics and vibrations; we like to have people from all over the world, and we like to have very high quality students and people. Also, we would like to have connections all over the world, across the whole field of acoustics. So it is this that we enjoy very much, but also while students are here, they study rigorously with their PhD, and their supervisors and many patents are created, so it increases the high level of academic and scholarship activities of this institute, together with spreading the context across the world in many forms of motivation.

Interestingly, the former point, in the Korean setting, stems from Korean cultural prejudice, which perceives Western cultures as superior. One Korean interviewee spells this out by saying, "Frankly speaking, Koreans still think those who have studied abroad or worked as a postdoc in foreign countries are better. I had my PhD in Korea. I think I should work as a postdoc in advanced countries, because I did not have my PhD in those countries, and Koreans do not recognize people who have no experience in advanced countries. I need this for recognition when returning to Korea." This cultural prejudice results in a pattern developing and a system being adopted that gives priority in employment and promotion and social privilege to Korean scientists and engineers who have educational and work experience in advanced Western countries. As a result, many Korean scientific actors actively seek opportunities to have research experience in American or British laboratories.

Comparison of Dynamics Involved in International Collaboration between Korean and British Scientists and Engineers

The dynamics involved in international collaboration are different in Korea, a newly developing country, and Britain, an advanced country. Korean scientists and engineers collaborate with advanced countries to obtain core knowledge and participate in advanced countries' laboratories for career building. A typical example is as one Korean interviewee says, "From the point of view of scientifically less advanced countries, obtaining information is important. Precisely speaking, international collaboration is actually a way of getting our scientific knowledge and technology transferred. In my field, this is the case. So, we definitely try not to collaborate with countries less advanced than us."

Regarding career building, this is a common example, a Korean medical scientist says, "But it is an important advantage for me to have research experience, in advanced countries, for my career track, for example, for changing my position. In the future, we need basic research, so this is our start." In addition, he states, "But we are very weak in basic research under our education systems. I think we cannot catch up with advanced countries in basic medical science, even if we had 100 years. We have more than 100 years' gap between Korea and America, in basic research. I think with Britain, we have more than 50 years gap in basic research." Concentration on scientific knowledge obtainment, reputation, research resources, and cultural prejudice are the main driving forces for Korea to engage in international collaboration.

On the other hand, British scientists and engineers have several reasons for participating in international collaboration, including fund-raising, sharing equipment, expertise exchange, and social networks. For example, a professor says, "There are all sorts of different programs, for example, the European Union has a program called: The Use of Large Facilities, so this is an expensive piece of equipment. You can go to some other countries so you can use some equipment." Another example is: "We usually collaborate because the projects tend to be international in scope. The sort of analysis we do doesn't just look at the UK, for example, it looks at other countries or aspects that are not simply confined to one country. So it's important to get international input and an international perspective." It is evident from the interview data that British scientists and engineers do not have sociological reasons (or forces), such as cultural prejudice and obtaining scientific competence and environments, as Koreans have, for participating in international collaboration.

Korean researchers' determinants of participating in British laboratories conform well to the inferior Korean status and the unbalanced structure in Korean science and technology. Most Korean interviewees identify Korean science and technology, in particular basic science and the capacity of basic research, as inferior to that in advanced science and technology. As a result, Korean science and technology copies, adapts, and modifies core science and technology for developing technology for product manufacturing. Nevertheless, their scientific fields vary (meteorology, physics, electronic engineering, biochemistry, food science, mechanical engineering, environmental science, molecular medicine, ocean science, the Liquid Crystal Display technology and physics, ship science, and physiology). One interviewee states, "With regards to science, Koreans learn advanced science and adapt knowledge produced by advanced countries, such as America, Britain, and some European countries. Korea is inferior to those countries." Another says, "The quality of Korean science and technology is very low, and we are copying advanced countries' science and technology."

It is interesting to find that researchers from Germany and South Africa do not have the collective social backgrounds and responsibilities of working for British laboratories. This contrasts well with the Korean researchers' reasons, to enter British laboratories. Furthermore, they consider Germany and South Africa to be very comparable to Britain, in terms of research quality. This is also very different from the Koreans' self-assessment of Korean research quality. A German scientist says, "Mainly personal reasons, because my girlfriend is English." When I ask him to compare research quality between Germany and Britain, he says, "Where the quality of the research is concerned, in both Germany and the UK, you get a very high quality of research. From my experience, I will say that equipment standard is higher in Germany, but as I said, quality of research, I believe, is very comparable." I do not have sufficient data for this, but this suggests a crucial difference from the Korean interviewees. Korean interviewees are certainly concerned with the inferior quality and status of Korean science and technology compared with those in Britain, and their reasons for having research experience in Britain reflect this.

Interestingly, comparison between Korean and British international collaboration, when they collaborate as an individual organization, indicates that knowledge production seems to be absent as a primary goal in Korean international collaboration. In the situation where Korean scientists and engineers collaborate with British ones in British laboratories as research students or researchers, they are part of the knowledge production system. I therefore emphasize the organizational point here. For example, a Korean meteorologist says, "I think the only way of collaborating with advanced countries is by us offering more funding to international collaborative projects. We pay expenses for inviting foreign researchers, and we pay when we visit foreign laboratories. The primary purpose is to get advanced knowledge and technology transferred." He continues,

> From the advanced countries' point of view, they conduct projects with their established methods and models for analyzing data when collaborating with us. They already have theories, analysis methods and models, and they do not produce anything new when collaborating with us. From the point of view of advanced countries, when they collaborate for new knowledge production, they do not need us, because they can do it for themselves. For this, our research quality should be better than advanced countries or be at the same level with them. And if the Korean weather observation laboratory was internationally excellent, like the British weather observation laboratory, then we could produce new knowledge. But this is not the case.

It is possible that Korean interviewees do not explicitly mention knowledge production as a goal for international collaboration in the sense that they may take it for granted. However, I do not think this is the case, because most Korean interviewees are fully aware that they are not compatible with their partners from advanced organizations in knowledge creation, and they specify that their primary goals are to obtain advanced knowledge and technology.

International collaboration is not simply determined by the nature of the scientific tasks to be completed. Sociocultural factors, including economic, organizational, cultural, and political factors, and the hierarchical international relations critically contribute to the generation of international collaboration.

Conclusion and Discussion

I have found from empirical data that collaboration between Korean research organizations and advanced organizations is not primarily undertaken for the purpose of knowledge production but, rather, that it benefits activities such as knowledge transfer, career building, model application to local conditions, or fund-raising. In such collaboration between Korean and advanced organizations, I could not trace synergetic effects for knowledge creation or technology innovations. I can clearly see in some collaborations that organizational alliances take place to create synergetic effects for knowledge production. Namely, collaborators put together individual parties' strengths and technical specialties, for example, some collaborations in the European Union.

Korean scientists and engineers' main aim in international collaboration (where Korean collaborators participate as members of an independent organization) is to obtain advanced knowledge and technologies from core scientists in exchange for funding for core knowledge production. The interview data show that Korean research organizations and scientifically advanced organizations are not compatible in research capacity. In this sense, collaboration loses its value as a mode of knowledge production. However, the incompatibility between them does not rest in the incompatible research quality derived from Korean collaborators' research incompetence. Korean interviewees believe that they were not inferior in research to their European partners. Most of the Korean interviewees told me that Korea has never had a lack of research manpower but that the research environment has been poor, and the Korean social system has not supported basic science and research. Thus, I suggest that the incompatibility should be reconsidered as stemming from factors such as the research environment, reputation, prejudice, social systems, and value systems in culture.

Korean science and technology is not believed to be a main international contributor to knowledge production, as my interviewees stated. In fact, Korea has been a latecomer to modern science and technology and has been busy adapting, learning, and absorbing itself into the system of Western science and technology. To survive in the highly competitive international economy, Korea has promoted and established an economic niche within applied technology and implementation techniques. This has created national wealth in the short term but ends up giving Korean science and technology an unbalanced structure without basic science and the capacity to carry out basic research. The Korean interviewees all described themselves as not engaged in core knowledge production but instead in core knowledge consumption and the application of the core knowledge to secondary technologies for end products and scientific activities for everyday life in Korea. They highlighted the imbalance of basic science and applied science, and basic research and technology in Korea, and said that they believed that this has prevented Korean science from reaching core status. Moreover, Korean society's survival strategies have shaped social systems and value systems in its culture, which has concentrated on money making, and have forced Korean scientific actors to participate in research that creates wealth. However, this kind of research does not enable Korean scientists and engineers to become contributors to knowledge production. As a result, Korea has not gained a reputation. In this sense, Korea, known as a technologically advanced and center-status (Glänzel 2001; Schott 1998) country, is located in the middle or gray area in center-periphery relationships in the scientific world system.

Some of the interviewees reported that scientifically advanced organizations had a negative attitude toward collaboration with Korean research organizations and sometimes requested a large amount of money to work with Korean collaborators. I think this indicates that the core scientific actors believe that Korean scientific actors and research organizations are inferior partners, whom superior organizations do not regard as ideal partners in highly competitive knowledge production. Both Korean scientific actors and their advanced collaborators may suffer from misconceptions about the relations between basic science, technology, and economic development. More precisely, core scientific actors' negative attitudes can be explained by the tension between the center attracting more ties and the middle and periphery attracting fewer ties. The center has enhanced self-reliance and deference from the middle and periphery, while the middle and periphery need to collaborate with the center for reward, recognition, and emulation.

What theoretical approach can explain this? I suggest that initially, Schott's (1998) center-periphery relationships in the scientific world system may enable us to understand the underlying system of the hierarchical structure, in science and technology. I believe that Traweek's (1992) reenactment of colonialist discourse is in line with the center-periphery relationships in the scientific world system. In relation to Schott's (1998) concept of ties between center and periphery, Korean scientific actors' educational or research training sojourn to center (British laboratories) for career building needs a distinctive attention as one important sociocultural factor contributing to international collaboration. This is closely related to cultural prejudice in the periphery where scientific elites who have a sojourn of education or research training in the center tailor their hegemony to protect their social privileges.

However, I have found from the interview data that I need to emphasize scientific actors' multiactivities and interdependency in international collaboration. Without this emphasis, I cannot elucidate the complementary way of collaborating. Complementary collaboration is structured by complicated interrelationships between basic science, technology, and economic development. Thus, center-periphery relationships in the globalization of science and technology are intricate and multifaceted, which can explain dynamic interactions between players in international relationships. I can find various flows of interactions, ranging from unilateral to multilateral interactions.

If the structure of hierarchical center-periphery relationships in the scientific world system can be developed as dynamic interactions between international players, I suggest that one should extend his or her notion of core-periphery relations, from that of a static and unilateral influence from core to periphery (in colonialist discourse), to a dynamic and varying flow of interactions between multiplayers (in multilayered center-periphery relationships in the globalization of science and technology).

Some players, close to middle or periphery positions, initiate new research and influence the interest foci of research. For example, Korean research organizations initiated what to research, based on their know-how of the market value evaluation of research. This influenced advanced countries', or multinational organizations', research directions. This shapes complementary collaboration, not in a way that collaboration combines expertise or technical skills but in a way that collaboration contains the division of research labor.

The empirical study highlights the intricate and multifaceted nature of international collaboration. The struggle over reputation and emulation drives international collaboration, when scientific actors and organizations, even in the case of those from the center, cannot find national alliances. One of the British interviewees, in environmental science and technology, showed how scientists in minority fields seek the reputation and resources of scientific research through international collaboration. Scientists who cannot obtain organizational support for reputation and research resources domestically stretch their efforts through international collaboration. This undoubtedly adds complexity to the multilayered center-periphery relationships in the globalization of science and technology.

An effect of multilayered center-periphery relationships in the globalization of science and technology might be the reconfiguration of global and local sciences, and greater recognition of middle science as distinct from the periphery, even if not fully belonging to the core, is vital for the continued development of the core science in those countries "traditionally," and increasingly unfairly, seen as being on the periphery. Korean scientists and engineers seem to be confused by the Janus faces of the globalization of science and technology. They make great efforts to belong to an international Western core scientific community and claim that they as individuals have already attained compatible scientific competence, but that they suffer from their nationally inferior scientific competence and believe their fate deprives them of the ability to be a competent global scientific actor. They also have a collective patriotic sense of their responsibility for escalating their national scientific status. Schott points out, "The formation of ties, especially across long distances and social differences, depends on the institutionalization of science. The formation of a global scientific community has been promoted by a worldwide institutionalization of the belief that validity of propositions is universal" (1998, 117). Despite the global scientific community, Korean scientists feel their inferiority as a scientific actor in the hierarchical scientific world system. In this sense, Korean scientific actors' local and global identities are contradicted. Thus, I believe that hierarchical relationships in the globalization of science and technology act as a crossing point between not only scientific actors' local and global identities but also, and more important, between their scientific and sociocultural identities. The globalization of science and technology in the context of multilayered center-periphery relationships should be viewed within the context of the power struggle between multilayered scientific actors' local status and global identities.

Notes

1. *Collaboration* in this article refers to collaboration in science and technology, its exclusive focus.

2. Leydesdorff and Etzkowitz contend, "In the 1990s, newly industrializing, deindustrializing and reindustrializing nations, somewhat to their surprise, find that they share a mutual interest in fostering knowledge based on economic and social developments requiring the creation of boundary-spanning mechanisms" (1997, 155).

3. Traweek maintains that a national scientific community is said to have emerged when it displays a fully developed "infrastructure" for science (1992, 104). She describes that an infrastructure includes (1) sustained funding for education and research at all levels, from elementary schools to national laboratories; (2) a certain proportion of the country's gross national product allocated regularly for scientific work; (3) a certain proportion of the country's population engaged in scientific work; and (4) scientists engaging in a high level of information exchange and documentation about their work. Unquantifiable, but much more significant, is the unqualified acceptance of a country's researchers' observations and analysis by a core country's scientists.

4. Zaltman (1968) describes how three major subsystems, the United States, the European countries, and Japan, have dominated the international communication network in high-energy physics (cited in Crane 1972). Interestingly, Zaltman (1968) observes that the Japanese has been relatively isolated from the flow of informal communications but that Japanese contributions to research have been acknowledged as frequently as contributions from the other two regions (cited in Crane 1972, 64).

5. Crane states that the United States and three European countries played important roles in mathematicians' networks. She observes that non-Western mathematicians did not appear to have much influence, and articles published in non-Western journals were much less likely to be cited, even once, than articles published in American and European journals (1972, 64-65).

6. Arrow's work is not included in the references in this article but is cited in Cameron and Le Bas (1999).

7. Sigurdson (1995) discusses the characteristics of dynamic change in the Japanese system of science and technology. He makes the point that Japan has become a leader in engineering

and technological innovation with weak links to science and without being at the frontier of technological research.

8. Gibbons et al. state, "There is clearly a relationship between excellence in science, especially basic science research, and international competitiveness in production, but the relationship is not linear or direct. To be a leader in science is neither a necessary nor a sufficient condition to be pre-eminent in producing technologies for the world market. As recent studies have emphasized, the skills and knowledge developed in the context of basic research are equally important in the innovation process (Pavitt, 1991, 1993; Williams, 1986)" (1994, 129).

9. Crane discusses the relationship between the role of social organizations and the logistic growth of knowledge in scientific research areas in her book, *Invisible College: The Diffusion of Knowledge in Scientific Communities.* Her work is a useful source of understanding with respect to the social interaction between scientific actors and the contribution of social organization to scientific knowledge production. She states,

> The growth of scientific knowledge, like that of most natural phenomena, takes the form of the logistic curve. The logistic curve has been fitted to the cumulative numbers of new publications appearing per year in scientific disciplines (Price, 1963). This means that the growth in numbers of new publications is passing through the following series of stages: (1) a preliminary period of growth in which the absolute increments are small, although the rate of increase is large but steadily decreases; (2) a period of exponential growth when the number of publications in a field doubles at regular intervals as a result of a constant rate of growth that produces increasing amounts of absolute growth; (3) a period when the rate of growth declines, but the annual increments remain approximately constant; and (4) a final period when both the rate of increase and the absolute increase decline and eventually approach zero. (1972, 2)

10. To explore the origins of big science, see *Big Science: The Growth of Large-Scale Research*, edited by Galison and Helvy (1992). This book discusses the social influences of big science from World War II to the postwar era. However, there is an absence of social influences in the post–cold war era, during which there was an acceleration of privatization and commercialization in science. In addition, "Large Collaboration: A Brief History" is in chapter 7 in Knorr-Cetina's book, *Epistemic Cultures: How the Sciences Make Knowledge* (1999).

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