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Holistic observation and monitoring of the impact of interdisciplinary academic research projects: An empirical assessment in Japan

Tomohiro Anzai [a,d], Ryoichi Kusama [b,c], Hiroyuki Kodama [b], Shintaro Sengoku [b,d,*]

[a] Translational Research Initiative, the University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
[b] The Institute for Integrated Cell-Material Sciences (WPI-iCeMS), Kyoto University, Yoshida-ushinomiyacho, Sakyo-ku, Kyoto 606-8501, Japan
[c] Department of Mechanical Engineering and Science, Graduate School of Engineering, Kyoto University, Yoshida-honmachi, Sakyo-ku, Kyoto 606-8501, Japan
[d] Pharmaco-Business Innovation Laboratory, Graduate School of Pharmaceutical Sciences, the University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

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ABSTRACT

Large-scale competitive research funding systems are currently being set up, and, in parallel, academic research projects aiming to integrate interdisciplinary research fields are being implemented at universities and research institutions. However, no objective methods have been established for readily evaluating academicians' productivity or the levels of integration between the disparate fields of interdisciplinary research projects. Such a methodology should be fundamental to the essential ex-post evaluation of policies, but currently, any evaluation of these projects relies merely on conventional qualitative methods, such as peer review. Indeed, with such subjectivity, it is hard to say whether academic institutions possess standardized management approaches for interdisciplinary projects.

This is an action research focused on two interdisciplinary academic institutional research projects, with the aim of objectively validating the key performance indicators for interdisciplinarity and productivity of research and testing the strategic fitness of each project. As for the indicator of interdisciplinarity, we have included the breadth of the research network coupled with the range of research fields. In this study, we have observed both consistencies and inconsistencies in governmental funding strategies, in the management of each project, and in the outcomes as measured by the key performance indicators. In addition, since these indicators could be measured quantitatively and recursively monitored during the project, they could also be applied readily to project management and to interim evaluation and benchmarking by the government.

1. Introduction

Approaches to the management of technology (MOT), as directed toward application and industrialization, have been systematically advanced in the technology field. This field encompasses such aspects as technological strategy, technological marketing, innovation, research and development (R&D), technical organization, technological risk management, and knowledge management (Kocaoglu, 1994; Kotnour and Farr, 2005). In addition, these approaches have recently expanded to research management from an enterprise perspective, to intellectual property management, as well as the management of network externality as represented by the notion of open innovation (Chesbrough, 2003; Tao et al., 2005). It is anticipated that significant new practices will ensue from enterprise R&D, as external collaboration continue to become a mainstream.

On the other hand, practical approaches to management of scientific research at universities and public research institutions have not been systematized. In fact, a discipline called "management of science" neither exists nor is it implicitly included in the meaning of MOT. The reason is that mainstream scientific research at universities and public research institutions has hitherto operated within closed communities of researchers, all of whom have the same specialty. Therefore, paradigm shifts have typically occurred only because of requests from within the group of scientists (Kuhn, 1962). In other words, the recognition of the need to act intentionally regarding management has been scarce until now.

Recently, this traditional scientific research system has been undergoing a necessary metamorphosis. Two transformational factors are drivers of this global dynamic:

1. Large-scale competitive funds and large-scale research projects
   The allocation of competitive funds has changed structurally, from funding small research groups to large-scale funding involving multiple research institutions and collaboration with

* Corresponding author at: iCeMS Complex 1, Yoshida-Ushinomiya-cho, Sakyo-ku, Kyoto 606–8501, Japan. Tel.: +81 75 753 9786; fax: +81 75 753 9759.
E-mail addresses: anzai@mol.f.u-tokyo.ac.jp (T. Anzai), ryoichi.kusama@kx7.ecs.kyoto-u.ac.jp (R. Kusama), hkodama@icems.kyoto-u.ac.jp (H. Kodama), ssengoku@icems.kyoto-u.ac.jp (S. Sengoku).

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industry. In the United States, for example, the National Science Foundation (NSF) has set up grants for research institutes, such as ERC (Engineering Research Centers) and the STC (Science and Technology Center) (Bozeman and Boardman, 2005). Also in Europe, the Framework Program (FP) (CORDIS, 2011), which is directed toward basic research, was established in the 1980s, and grants aiming for the commercialization of technology have been launched across the European region, such as the European Research Coordination Action (EUREKA, 2011. In Japan, large-scale competitive research funding systems have been successively expanded and implemented, starting with Exploratory Research for Advanced Technology (ERATO) in 1981 and Core Research for Evolutional Science and Technology (CREST) in 1995 from the Science and Technology Agency (currently merged with the Ministry of Education, Culture, Sports, Science and Technology (MEXT). These initiatives have been expanded by the Policy for Structural Reform of Universities (National Universities) (June 2001) and the Third Science and Technology Basic Plan (March 2006). These approaches aim to promote the creation of universities that are internationally competitive, not only by promoting industry–academia collaboration but also by concentrating their funds at research and educational institutions with the world's highest standards, thus facilitating the development of creative human resources that further enhance the level of research competency to lead the world. Specifically, implemented grant projects include the following: 21st Century Center of Excellence (COE) Program (FY 2002–2008, 11 fields, 274 projects), Global COE Program (FY 2007–2013, 11 fields, 140 projects), World Premier International Research Center Initiative (WPI) Program (FY 2007–2016, 6 projects), Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST) Program (FY 2010–2014, 30 projects) (Oba, 2008).

2. Interdisciplinary and cross-field integration
The significance of promoting interdisciplinary research has been emphasized in recent science/technology policy, and numerous organizational approaches aim at materially accelerating interdisciplinary research. New research centers or institutions have been established for this explicit purpose. They provide not only an internal organizational framework for interdisciplinary research, but also offer an external interface with society to support research activities (Bozeman and Boardman, 2003; Etzkowitz and Kemelgor, 1998; Stahler and Tash, 1994). For promoting integration and research collaboration, a number of factors have been identified as important (Klein and Porter, 1990; Porter et al., 2006), especially the following: (i) reinforcement of political inducement and public support, (ii) reinforcement of self-sustained management at corresponding research institutions, and (iii) reinforcement of training of key researchers with broader perspectives. With regard to (i), which involves policy guidance, initiatives such as WPI and FIRST Programs have been recently launched in Japan, both of which position the promotion of interdisciplinary collaboration and cross-field integration as a central objective. In regards to the current situation of (ii), the management of a particular research institute is typically dependent on their individual effort and is, therefore, ad-hoc; hence, a flexible and scalable management methodology remains necessary to drive effectiveness and efficiency. This requirement parallels the way corporate productivity has been enhanced by a shift from a centralized approach to a globally networked internal (transnational) model (Bartlett and Ghoshal, 1998). The training of key researchers, (iii), is now becoming recognized as a key requirement in this changing environment, to be addressed explicitly by academic institutions.

In this paper, we deliberately focus on academic research projects which aim to achieve interdisciplinary and cross-field integration. Little empirical analysis exists in this field in the context of theories of management of science and technology or innovation management. The authors believe it should be a significant concern that, even though large amounts of public funds have been invested for promoting academic integration and collaboration, a basic policy for management or methodology has not been well established at the academic research institutions which gain such funding.

We divided this discussion into six sections. Section 2 describes the existing literature, while Section 3 outlines our research procedures. Section 4 provides the empirical results from our examination of two cases of institutional interdisciplinary research projects from Japan. In Section 5, we evaluate the broader applicability of our proposed framework with particular reference to its scalability and significance to research strategy, as well as to the practical, operational, and organizational management of any projects. Finally, Section 6 indicates how this research needs to be further developed to provide a flexible and holistic management framework for objectively assessing the impact of research initiatives.

2. Existing research in review

2.1. Interdisciplinary integration mechanism

Several academic research paths consider the integration of interdisciplinary initiatives. One such path consists of theories developed through case studies for institutional and project management.

With a focus on institutional management, internal and external preconditions and organizational change for interdisciplinary research have been explored (Klein and Porter, 1990; Hage, 1999; Hage and Hollingsworth, 2000). The case analysis of the creation of a new discipline of "biomedicine" at Institut Pasteur in France noted that the development of carrier paths in new interdisciplinary fields enabled the institution to integrate two disciplines (Hage and Mote, 2008). Heinze et al. (2009) also articulated the organizational factors that influence the creativity of organizational research activities by analyzing 20 case studies of prizewinners. Corley et al. (2006) focused on a multi-institutional collaborative project and postulated a two-stage model: (i) establishing an interdisciplinary research field as a new discipline and (ii) establishing a research organization for a new discipline. Corley et al. further defined the requirements to be fulfilled at each stage. From the viewpoint of project management, in-depth discussions on institutional challenges were discussed by classifying the projects by their size and by their technical and organizational complexity—i.e., variety of disciplines (Jordan, 2006; Shenhar, 1998, 2001).

Another research avenue has been to describe individual behavior at institutions with a collaborative process. A comparative analysis of behavior patterns (e.g., daily usage of time) between researchers at academic interdisciplinary research institutions and researchers belonging to traditional departments showed that the proportion of actual time spent on collaborative research was higher at interdisciplinary research institutions (Boardman and Corley, 2008). However, in either case, no analysis has verified what kind of approaches at research institutions satisfies the requirements of interdisciplinary research formation or creates changes in behavior at the individual researcher level. Haythornthwaite (2006) verified what kind of benefits researchers themselves expect in collaboration between cross-field researchers. As a result, it became clear that in the natural sciences, exchanging information on experimental methods, implementing collaborative research, and sharing experimental results were listed at the top of the ranking, whereas creation of research ideas or formation of personal networks was rarely emphasized. However, a correlation between action and result in interdisciplinary research, such as how these collaborations lead to actual material improvement in outcomes, was not verified.

2.2. Development of key performance indicators (KPIs)

Quantitative analyses of the R&D activities of enterprises via a questionnaire survey have been undertaken by Yale Survey I/II (Levin et al., 1987) and Carnegie–Melon Survey (Cohen et al., 2000) in the United States and the Community Innovation Survey (CIS) in Europe (EUROSTAT, 2001), followed by the Japanese National Innovation Survey (J-NIS, 2003). These empirical approaches established at a macro level, a basis of research on innovation management in each area; however, methodologies for evaluating research institutions through activity measuring have not been established.

Moreover, while measures (quantitative evaluation based on the number of cited papers or science linkage) for evaluating academic outcomes based on published research papers have long been developed, measures for quantitatively and objectively evaluating the degree of individual interdisciplinarity and/or institutional collaboration have not yet been established for practical use at the institutional management level.

Within the literature, there are a number of studies, to date, which analyzed the interdisciplinarity of academic research papers, using various indicators that represent the diversity of the ecosystem and the market (Kajikawa and Mori, 2009); Porter et al., 2007; Rafols and Meyer, 2010; Stirling, 2007). In evaluating interdisciplinarity, a number of indicators were utilized: "variety," which referred to the number of academic disciplines; "balance," meaning evenness of the distribution of disciplines; and "disparity or similarity," which alluded to the degree of difference between disciplines. It was found that each indicator individually had a low correlation, but while there was no indicator capable of correctly and completely evaluating interdisciplinarity, it was proposed that a certain indicator can be used complementarily with other indicators to predict impact. The critical next step is to apply such indicators to an actual research operations and evaluation beyond discussing their accuracy and predictive capabilities. Moreover, with objective indicators to measure interdisciplinarity, one might hypothesize that a method for evaluating the effect of managerial approaches at an organizational level would be feasible.

Specifically, it is important to objectively identify the effect of large-scale competitive research funds not only on the academic research papers published, but also on the patents attributable to such research projects. To achieve this, the impact of observed factors (self-selection bias) and of unobserved factors (analyzed by difference-in-differences, DID (refer to Section 3.4)) needs to be distinguished and statistically controlled. Furthermore, since measures used for evaluation differ across different fields, a holistic evaluation approach able to capture the characteristics of each field needs to be developed (Lee, 2005). Porter et al. (2010) employed an interdisciplinarity metric for their tools in characterizing National Science Foundation (NSF) educational research awards. Preliminary analysis for comparing the interdisciplinarity of grant application and publications has shown that the awards actually facilitated interdisciplinary research (Porter et al., 2010). An evaluation framework, which is executable at the institutional level, independent of the field of research remains to be developed. It should be capable of verifying different approaches to facilitate interdisciplinary research, for example, institutional management policy and activities, which actually serve to translate how funding policy yields material research outcomes.

A necessary first step is a consistent definition. As a pragmatic approach in the United States, the U.S. National Academy of Sciences ("Facilitating Interdisciplinary Research", 2004) defined interdisciplinary research as a research activity that creates a new academic field by integrating information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice.

2.3. Current situation in Japan

With the increasing focus on interdisciplinary research, such as the WPI and FIRST Programs, the importance of a coherent and objective evaluation process has been pointed out to maximize the impact of competitive funds. In 2003, a comprehensive evaluation of MEXT revealed that Japanese scientists were requesting the clarification and revision of prior, interim, and ex-post evaluations, with suggestions such as "selecting a fair and clear problem," "reflecting the result of interim evaluations," and "picking up superior points in a positive manner upon evaluation." Negative opinions have recently been expressed on ex-post evaluation of research performance. Indeed, the current situation is such that not only individual research projects, but also research policy, are being questioned in open budget debate. For example, in MEXT policy, with regard to the 21st Century COE Program in 2008, in the section on results with regard to taking inventory, numerous opinions were contributed, such as "the purpose and effect is unclear and the number is too large, and is thus unnecessary in current state."

In response to this situation, the Outline Policy For Government Research and Development Evaluation specified the importance of a "clear and specific set evaluation criteria in advance, and announcement to evaluation subjects," and in particular regarding the evaluation, proposed the necessity to "make an effort to utilize specific indicators and quantitative values" (The Prime Minister of Japan, 2008). Some specific simple metrics, "Quantitative indicators showing the use of patents etc. and objective methodology to evaluate the quality of published research papers" were suggested. The necessity for developing a scheme for transparent, third party evaluation has been pointed out (SCJ, 2008). However, traditional methods, such as peer review, still tend to be widely used, and new objective evaluation methods, even for evaluating interdisciplinarity, are not yet adopted.

2.4. Objective of this study

This investigation is seminal in that it defines interdisciplinary research based on an empirical study with extended interdisciplinarity indices, which can be practically introduced at the institutional level and explicitly reflected in its management. The results obtained have been verified through management reviews. This combinatorial analysis on actual research projects to investigate the relationship between management actions and the resulting indices can be used only for this empirical study. Given the fact that interdisciplinary research initiatives have only recently emerged in Japan, this study successfully tracked the trajectories of these projects. On the other hand, approaches to operationalizing this framework to reflect actual management policy have not been discussed, thus remaining as a future challenge.

3. Research methodology

3.1. Selection of research subjects

For the empirical analyses, two interdisciplinary research projects at two Japanese academic research institutes, (i) the University of Tokyo, Center for NanoBio Integration (CNBI) and (ii) at Kyoto University, the Institute for Integrated Cell-Material Sciences (iCeMS) were selected and investigated. Details of these institutions are described in Table 2.

3.2. Selection of control groups

Control groups were selected that included researchers not belonging to either of the investigated groups. These groups mirrored the investigated groups, having the same number of researchers with equal proportions of each job class. Researchers were selected at the same research institution and research faculty (or sub-department if any) as researchers of the investigated groups in order to match environmental factors. Where there were multiple candidates for the control groups, researchers were randomly selected against the order of the Japanese alphabet. If it was not possible to select a comparable researcher with an equivalent position for a given control group, a higher ranking position was selected as the alternative (e.g., an associate professor instead of a senior lecturer).

3.3. Setting of evaluation indicators

As the basis for the evaluation indicators, the evaluation period comprised two periods: 2005–2007 and 2008–2010 for iCeMS and 2000–2004 and 2005–2009 for CNBI. Published papers by each researcher were analyzed with the Scopus database (Elsevier's database of research papers). Previously, the Web of Science (WoS hereafter) by Thomson Reuter has been employed (Porter et al., 2010; Rafols and Meyer, 2010). Scopus was used for this study, as it assigns journals to more specific research fields, with 27 major thematic categories as well as to 300+ specific subject categories, whereas WoS allocates journals into 22 broad fields and about 250 subject categories. The research was not filtered by type of paper (i.e., whether it is an article or not) nor by type of author (i.e., whether the subject is the first author or not).

3.3.1. Scope indicators of the research field

3.3.1.1. Interdisciplinarity Index (Herfindahl–Hirschman index: HHI). To evaluate the interdisciplinarity of each researcher, the following formula (Hall et al., 2001; Kajikawa and Mori, 2009; Stirling, 2007; Rafols and Meyer, 2010) was employed:

$$\text{Interdisciplinarity index} = 1 - \sum_{i} \times \left(\frac{\text{Total Number of Published Literatures in Journals of Field } i}{\text{Sum of All Fields for Number of Corresponding Papers in Each Field}} \right)^2$$

This formula has been widely used in diversity evaluations of patents held by enterprises. The value of this index ranges from 0 to 1, where a value closer to 1 indicates that the corresponding research fields of each researcher are more diverse. The research field of each journal was defined using 27 research field classifications listed in Scopus (2011). In some cases, one journal falls under multiple research fields. This index is an indicator reflecting the difference in the number of research papers according to field. Since the research field assigned to a journal posting for a research paper is not limited to one, the sum of all fields for the number of corresponding research papers in each field for each researcher will be larger than the number of all published research papers.

One might argue that HHI reflects "variety" and "balance," but not "disparity" (Section 2.2), as defined in Stirling's index (Kajikawa and Mori, 2009; Rafols and Meyer, 2010). However, we selected HHI as the algorithm in this study for the following reasons: (i) previous studies revealed that there are quite high correlations between the results calculated by HHI and Stirling's indexes; (ii) classification of research fields by Scopus has seven layers of specificity level, and the interdisciplinarity could be calculated at a higher specificity level (27 and 335 classes in the first and second levels followed with further breakdown according to the ASJC Code list 2004); (iii) adding coefficients to put weight on the research fields at the institutional research objectives, HHI could also evaluate outcomes with regard to institutional directions, and (iv) given that the research field classification is universal, and the calculation process of HHI is much simpler than that of Stirling's index. Therefore, it could serve as an alternative and as a more feasible option for wide deployment among research institutions in any field.

3.3.2. Scope indicators of the research network

3.3.2.1. Number of joint papers (total number and ratio to all researchers' published papers). Joint papers are defined as research papers published with multiple authors belonging to the same project in iCeMS/CNBI from different laboratories. Note that joint papers by researchers belonging to the same laboratory were excluded from the number of joint papers. As the indicator of the number of joint papers, the average number of joint papers per year, per researcher during each period, was calculated.

3.3.2.2. Number of affiliated institutions (total number and number per paper). Based on the affiliation information for the author of a research paper, the total number of research institutes to which the authors of the papers belong was defined as the number of affiliated institutions. As an indicator of the number of affiliated institutions, two metrics were calculated during each period: (i) the total number during the period and (ii) the number per paper, for each researcher. For instance, if every researcher in an institution publishes 10 papers in 5 years, in which the average number of research institutions listed is 5, indicator (i) is 50 and indicator (ii) is 5.

3.3.2.3. Number of affiliated regions (total number and number per paper). The country of the research institution where the author of each paper resides was defined as the affiliated region. As the indicator of the number of affiliated regions, two metrics were calculated: (i) the total number during the period and (ii) the number per paper, for each researcher.

3.3.3. Indicator of publication productivity

3.3.3.1. Number of research papers. The number of research papers was defined as the number of research papers published in journals included in the Scopus database. As the indicator of the number of research papers, the total number of published research papers during the period was measured for each researcher.

3.4. Statistical analysis

Using the indicators described in the previous section, statistical analyses were performed on the investigated groups, CNBI and iCeMS, as well as the control groups for each. Specifically, for both the investigated and control groups, data from two periods, pre- and post-start of the projects, were tested for normality of sample distribution using the non-parametric, Kolmogorov–Smirnov test. As a result, for either combination of the corresponding set of investigated group and control group or the corresponding set of pre- and post-start of the projects, either one of the corresponding data was $p<0.05$, and thus normality could not be guaranteed (data not shown). Non-parametric analysis was therefore necessary for subsequent intergroup comparisons.

In an intergroup comparison of the pre- and post-start of the projects, a Wilcoxon signed-rank test was performed in order to compare the corresponding data of the same researcher. For each period, pre- and post-start of the projects, a Mann–Whitney *U* test was performed to compare the investigated group and the control group.

For a comparison with the control group, the difference in differences (DID) method was employed. The set up of DID method was setup such that outcomes were observed for two groups for two time periods. One of the groups was exposed to a treatment in the second period but not in the first period, while the second group was not exposed to the treatment during either period. In the case where the same units within a group are observed in each time period, the average gain in the second (control) group is subtracted from the average gain in the first (treatment) group. This removes biases in second period comparisons between the treatment and control groups, which could be the result of permanent differences between those groups, as well as biases from comparisons over time in the treatment group, which could be the result of trends. Thus it can estimate the net effect of participating in the institution against each indicator, correcting the effect of time. Data from the pre- and post-start of the projects were used for estimating the simple linear model by regression analysis:

$$\text{Indicator}=\gamma_0+\gamma_1 d^{\text{treat}}+\gamma_2 d^{\text{after}}+\delta d^{\text{treat}} d^{\text{after}}+\varepsilon$$

Indicator represents evaluation indicators such as "Number of affiliated institutions" or "Number of research papers," etc. which were described in the previous section. d^{treat} represents a dummy variable that captures possible differences between the treatment and control groups prior to the generation of the institute and that will be equal to 1 when affiliated with the institution. d^{after} represents a dummy variable that captures aggregate factors that would cause changes in Indicator even in the absence of the generation of the institute and that will be equal to 1 after the generation of the institute. The coefficient of interest, δ, represents the DID estimate that multiplies the interaction term $d^{\text{treat}}d^{\text{after}}$ which is the same as a dummy variable equal to one for those observations in the treatment group in the second period

3.5. Expert review

To conduct a qualitative review on the measured KPIs and key management actions of each project, four PIs were selected as reviewers. Two of them were members of the management committee for CNBI, and the other two were from iCeMS. An hour-long structured interview for each reviewer was conducted using the same questionnaire format and the same data set as for Tables 3 and 4.

4. Results

4.1. Theoretical framework for interdisciplinary research projects

With the development of new indicators for interdisciplinary research (Kajikawa and Mori, 2009; Porter et al., 2007; Rafols and Meyer, 2010), an overall framework encompassing multiple constituency viewpoints, such as the government that finances interdisciplinary research projects, has begun to be addressed (Porter et al., 2010). Accordingly, a theoretical framework was created that includes factors that may affect the management policy of each project and outcome of interdisciplinary research projects (Fig. 1).

At the outset of a project, the funding agency designs and organizes their research grants that could reinforce the initiative of their science policy, and each institution proposes research projects based on the specific application requirements. Each selected research project decides its own management policy and makes internal management decisions, such as allocating research expenses and human resources, and planning conferences or events in order to achieve the proposed goal. As a result, the progress and outcome diagnostics of the research can be quantitatively represented by the outcome indicator. In some interdisciplinary research projects, the promotion of integration per se between researchers, in particular those belonging to different fields, becomes one of the goals of the project. These parameters cannot be sufficiently assessed using existing outcome indicators, such as the number of research papers or the number of cited papers of papers.

Among the KPIs, we proposed two specific indicators to address this omission: specifically, (i) an Interdisciplinarity Indicator representing the breadth of the research field or research network, and (ii) a Publication Productivity Indicator consisting of the number of research papers or the number of citations in other papers. In addition to these metrics, other measures related to the intellectual property and practical commercialization cases will be relevant additional KPIs for applied research. These new Interdisciplinarity Indicators are positioned as surrogate indicators of the overall productivity of the research project. In particular, they are comprised of parameters such as the number of joint papers between affiliated researchers or the number of affiliated agencies and countries of authors in joint papers.

Our empirical analyses also focused on the degree to which the project strategy affected Interdisciplinarity Indicators and a Publication Productivity Indicator.

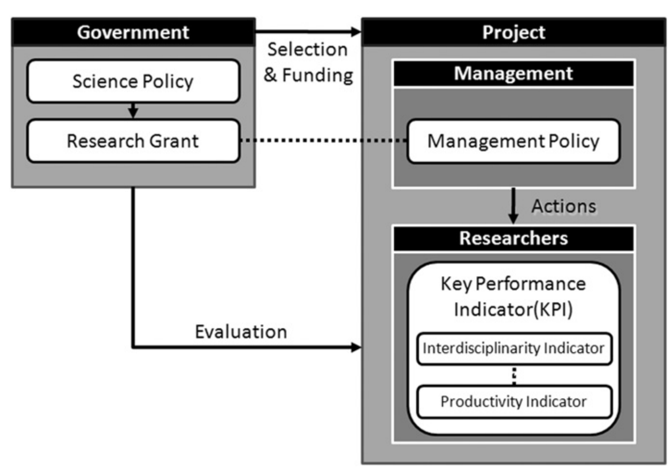

Fig. 1. Theoretical framework and factors that may affect the management policy and outcome of interdisciplinary research projects. The management policy for each selected research project is decided according to the specific requirements set by the governments via the funding agency. Two specific indicators are selected to measure the performance of researchers, specifically the following: (i) Interdisciplinarity Indicators representing the extensity of the research field or research network, and (ii) a Publication Productivity Indicator, consisting of the number of research works or the number of papers cited in the literature.

4.2. Government side strategy

In order to understand the government's strategy for large-scale and interdisciplinary-type research grants, we conducted a paper-based survey regarding research policy and application guidance for research grants.

"Research and Development in a New Integrated Field Focusing on Nanotechnology and Materials" is the name of a project commissioned by the Research Promotion Bureau of MEXT, with the specific objective of exploiting the high technological potential of nanotechnology in Japan. The goal of this project is to establish industry–academia collaborative research systems and integrated research centers to promote R&D strongly (Table 1). According to the application requirements announced by MEXT in April 2005, there were three general qualifications for applied research projects. First, it is desired that a goal not only develops technological seeds but also commercializes the research outcome. Second, bidirectional research communication between researchers, regardless of their existing fields, is desired in the process of building the research centers. Concerning these issues, the Program Director for this project, Dr. Sawaoka, notes, "[I]n this project, we aspire to form the world's preeminent powerful research centers that accomplish consistent R&D, which is strongly fixed on practical applications of the research outcome. We hope to obtain achievements that can be attained only by an advanced basic research platform in the integrated area of the nanotechnology field and other fields to generate new research institutes" (JST, 2006). Third, the generation of global open research centers is desired, with establishment of international collaborative activities (such as hosting symposiums) to facilitate the cross-fertilization of ideas and activities. In the same vein, the importance of recruiting leading foreign researchers and facilitating human resource exchange among industry, academia, and government are also to be encouraged.

Based on the Third Science and Technology Basic Plan (issued by the Cabinet Office, March 28, 2006) and the "Comprehensive Strategy for Creating Innovation" (issued by the Council for Science and Technology Policy, June 14, 2006), MEXT established the WPI Program in FY 2007. The WPI Program provides priority support for projects aimed at creating top-level international research centers staffed at their core with the world's leading researchers (Table 1). By achieving a very high research standard and providing an excellent research environment, the centers are asked to project a level of "global visibility" that further attracts top researchers in a virtuous cycle from around the world. The Japan Society for the Promotion of Science, a funding agency commissioned by MEXT, conducts grant selection and project assessment, and performs other administrative functions in accordance with the guidelines established by the Ministry.

The WPI Program's aims are clear and ambitious to create globally visible and internationally connected, "best in class" research centers in Japan, in which the world's finest brains gather, outstanding research results are generated, and talented young researchers are nurtured for the future. To fulfill these goals, WPI research centers are expected to be highly innovative in both concept and practice. Thus, the following four conditions are essential to being a WPI center: (i) top quality of science, (ii) internationalization, (iii) breakthroughs by fusion studies, and (iv) reform of research systems.

As of December 2010, MEXT had selected the following five research centers to be funded under the WPI Program: Advanced Institute for Materials Research (AIMR), Tohoku University; Institute for the Physics and Mathematics of the Universe (IPMU), the University of Tokyo; Immunology Frontier Research Center (IFReC), Osaka University; International Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science (NIMS); International Institute for Carbon-Neutral Energy Research (I^2CNER); iCeMS, Kyoto University.

4.3. Case study of CNBI and iCeMS

For the empirical analyses two academic research institutes in Japan, the University of Tokyo, Center for NanoBio Integration (CNBI), and Kyoto University, the Institute for Integrated Cell-Material Sciences (iCeMS) were investigated. Documents related to project management, organization, research fund allocation, human resources, operation of events and meetings were analyzed to understand the strategy of each institution that carries out R&D while receiving research funding to achieve the objectives set by the government. For CNBI, for example, keywords were extracted from such documents as project proposals for MEXT (May 2005), presentation files for interviews (June 2005), interim reports (July 2010), and their presentation file for the final review (August 2010). In contrast, for iCeMS, keywords were extracted mostly from its website.

In response to application requirements from the government, CNBI has proposed the implementation of several specific activities in the process of establishing its research center (Table 2). Initially, three development groups were proposed to promote R&D for the practical commercialization of research outcomes. Specifically, (i) a Bioinspired Nanomachine Group for integration of molecular assembly and NEMS technology, (ii) a Nanobiosensing Group that would carry out a precise space-time analysis of polycentric biological information, and (iii) a Cell Therapy Group to invent nanotechnology materials applicable for therapeutics. From the collaborative and competitive research initiatives resulting from these three groups, original diagnostic devices to take advantage of microfabrication technology and DDS

Table 1
Government grants for promoting interdisciplinary research projects.

	Research and Development in a New Interdisciplinary Field based on Nanotechnology and Material Science	The World Premier International Research Center Initiative (WPI)
Ministry in charge	Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan	Ministry of Education, Culture, Sports, Science, and Technology (MEXT), Japan
Number of projects	2 projects	6 projects
Period	5 years	10 to 15 years
Funding scale	Less than JPY 0.75 billion per year	JPY 7.2 billion in FY 2010
Funding objectives	Pursue research not only for developing technological seeds but also for achieving practical application of technology	Create top world-level research centers staffed with the world's leading researchers
	Aiming at inter-disciplinary technological cooperation and integration	Create globally visible and internationally open top-level global research centers in Japan
	Generation of globally open research institute with participation of excellent foreign researchers	Pursue top quality of science, internationalization, breakthroughs by fusion studies, and reform of research systems

Table 2
Interdisciplinary academic research projects.

	Center for NanoBio Integration (CNBI)	Institute for Integrated Cell-Material Sciences (iCeMS)
Organization	University of Tokyo	Kyoto University
Project leader	Kazunori Kataoka (Professor of Graduate Schools of Engineering and Graduate School of Medicine)	Norio Nakatsuji (Professor of Institute for Frontier Medical Sciences)
Total funding size	JPY 2.59 billion	JPY 4.94 billion as of FY 2010
Annual average	JPY 0.51 billion	JPY 1.35 billion in FY 2010
Number of researchers (PIs)	114 (33) as of the end of FY 2010	174 (18) as of the end of FY 2010
Management strategy	Create three cross-disciplinary groups (i.e., groups of Bioinspired Nanomachines, Nanobio Sensing, and Cell Therapy) that constitute researchers with a wide variety of specialties	Create new integrated disciplines of cell-material sciences on the basis of the cross-disciplinary fields of chemistry, physics, and cell biology
	Principal of sharing the research resources among CNBI researchers to increase unity of CNBI	Become a global hub of career development for scientists
	Setting up events such as Research Camp with the participation of all researchers to achieve smoother communication between researchers, and to promote research collaboration within CNBI	Contribute to human wellness in environmentally friendly chemistry by meso-control, detoxification and drug synthesis in the body, and regenerative medicine by controlling stem cells with smart materials

(drug delivery system) utilizing nanotechnology were developed. Three main specific approaches were taken to facilitate cross-field collaboration and integration: (i) assembling three groups constituted of researchers from different fields, regardless of department or course framework; (ii) sharing research resources for achieving a sense of unity among all researchers; and (iii) the hosting events to explicitly promote research integration, such as research camps in which all researchers are expected to participate. Concerning international expansion, cooperation with overseas nanobio institutions, such as the California Nanosystems Institute (CNSI) of California or Nanosystems Initiative Munich (NIM) in Germany, were carried out, as well as proactively organizing international symposiums and other meetings. Other characteristic activities include human resources systems in which young researchers were given specially appointed posts and treated as important focal forces in the institution, and public relations profiling activities whereby information regarding research at the institution is widely distributed in a timely fashion to multiple constituencies through websites and newsletters.

The iCeMS was established at Kyoto University on October 1, 2007, under the WPI Initiative. The iCeMS strives to create new integrated disciplines of cell-material sciences, creating mesoscopic science and technology based on atomic and molecular interactions occurring on the scale of 5–100 nm, through cross-disciplinary approaches across chemistry, physics, and cell biology, and to become a global hub for scientists' career development (Table 2).

To be more precise, research conducted at the iCeMS is built around two key concepts: they intend to establish the stem cell sciences and technologies and mesoscopic sciences and technologies. This strategic intent aims directly at human wellness in three main areas: environmentally friendly chemistry, detoxification and drug synthesis in the body, and regenerative medicine by controlling stem cells with smart materials.

4.4. Measurement of KPIs

Based on an understanding of the management policy of the government and of each institute, Interdisciplinarity Indicators were measured first. The effects of research funding and management policy on interdisciplinarity and productivity were measured by the following three approaches. The first is a comparison of parameters between the period before the start of the project and the same length of period during the project. In this way, the degree of growth of indicators between pre- and post-start project periods can be investigated. The second consideration is a comparison with a group not accepting any funding support, such as from CNBI or iCeMS. In this way, the degree of funding effect can be estimated. The third dimension of overall impact is the quantification of project effect through a method called DID, which excludes increases in parameters caused by other factors; then the actual effect by the targeted research funding (Section 3.1) and the effect of these projects on the indicator for each researcher per year can be quantitatively calculated.

Improvement of the Interdisciplinarity Indicator of CNBI was observed over time, especially expressed by an increase in the number of joint papers published by CNBI researchers (Table 3). This indicator was also significantly higher compared to the control group, suggesting that CNBI gave a large contribution to improving the number of joint papers. A significant difference was also found for this indicator when comparing the CNBI group before the project period with the control group, suggesting that CNBI consists of a group of researchers who are relatively experienced in collaboration. The DID analysis confirmed that the increase in the number of joint papers, excluding the natural increase from not being associated with the CNBI fund, averaged 0.466 papers per researcher, per year. This increase in the Interdisciplinarity Indicators suggests that CNBI had a positive effect on the interdisciplinarity of their affiliated researchers.

Furthermore, it is important to note that the effect of CNBI does not promote a qualitative change in terms of the scope of its publications. Thus, the number of fields or the number of affiliated organizations and the number of countries, by paper, of CNBI researchers were also analyzed. No significant change was seen between pre- and post-start of the CNBI project, suggesting that no large change occurred in the quality of individual research papers in terms of interdisciplinarity. Although a significant improvement was detected in the number of affiliated organizations and the number of affiliated regions between, before, and during the period, there was no significant difference with the control group (no CNBI effect).

When the Publication Productivity Indicator of CNBI was measured, no significant difference was detected in any item between the CNBI group and the control group before the funding period. In other words, it was confirmed that before the start of the project, the CNBI group consisted of researchers having research paper productivity almost equal to that of the control group. It was confirmed that the number of research papers significantly increased in terms of annual change. However, there was no significant change in the comparison with the control group. Through the DID analysis, the CNBI group showed higher numbers of publications by 0.011 papers per year, per researcher. Moreover, when the number of citations was compared between

Table 3
Measurement of Interdisciplinarity Indicators and Publication Productivity Indicators of CNBI.

KPI		Unit	CNBI		Control		CNBI Before/ After		Before CNBI/ Control		After CNBI/ Control		Effect of project		
			2000–2004	2005–2009	2000–2004	2005–2009									
			Mean (S. D.)	Mean (S. D.)	Mean (S. D.)	Mean (S. D.)	Effect	*P* Value	Effect	*P* Value	Effect	*P* Value	DID Value	Effect	*P* Value
Interdisciplinarity Indicator	Extensity of research field														
	Interdisciplinary Index	Index	0.687 (0.204)	0.763 (0.132)	0.654 (0.219)	0.713 (0.124)	**	.009		.472	*	.016	-0.015		.740
	Extensity of research network														
	Joint papers	Ratio	0.05 (0.08)	0.06 (0.07)	0.03 (0.09)	0.01 (0.03)		.247	**	.006	***	.000	0.043	*	.016
	′	Total	2.43 (4.21)	4.23 (5.10)	0.66 (1.94)	0.34 (0.59)	**	.007	**	.006	***	.000	0.446	*	.010
	Affiliated organizations	Per Paper	2.50 (0.88)	3.00 (0.86)	3.09 (1.59)	3.27 (1.30)	***	.000		.160		.668	-0.059		.818
	′	Total	62.5 (58.6)	82.1 (59.0)	35.5 (47.1)	56.3 (49.9)	**	.004	*	.046	*	.037	1.794		.644
	Affiliated regions	Per Paper	1.15 (0.15)	1.12 (0.15)	1.15 (0.17)	1.16 (0.17)		.914		.995		.260	-0.094		.207
	′	Total	3.34 (2.74)	3.57 (2.69)	2.60 (2.28)	3.51 (3.17)		.428		.252		.747	-0.251		.257
Publication Productivity Indicator	No. of research papers	Total	37.9 (33.7)	55.5 (44.5)	22.7 (27.9)	39.4 (36.3)	**	.001		.066		.050	0.011		.993

Notes: $N=35$ (PIs). $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$. S.D.=standard deviation.

Table 4
Measurement of Interdisciplinarity Indicators and Publication Productivity Indicators of iCeMS.

KPI		Unit	iCeMS		Control		iCeMS Before/ After		Before iCeMS/ Control		After iCeMS/ Control		Effect of project		
			2005–2007	2008–2010	2005–2007	2008–2010									
			Mean (S. D.)	Mean (S. D.)	Mean (S. D.)	Mean (S. D.)	Effect	*P* value	Effect	*P* value	Effect	*P* value	DID value	Effect	*P* value
Interdisciplinarity Indicator	Extensity of research Field														
	Interdisciplinary Index	Index	0.668 (0.205)	0.686 (0.208)	0.605 (0.236)	0.667 (0.166)		.722		.290		.296	-0.091		.141
	Extensity of research network														
	Joint papers	Ratio	0.04 (0.01)	0.06 (0.01)	0.00 (0.01)	0.00 (0.00)		.061	**	.006	***	.000	0.042		.073
	′	Total	0.27 (0.57)	0.61 (0.74)	0.06 (0.24)	0.09 (0.38)	*	.017	**	.006	***	.000	0.071		.262
	Affiliated Organizations	Per paper	2.89 (1.04)	3.73 (1.13)	2.66 (1.13)	2.82 (1.12)	***	.000		.359	**	.006	0.055		.862
	′	Total	53.4 (53.9)	60.6 (63.5)	47.1 (52.0)	52.2 (49.9)		.520		.521		.959	0.727		.861
	Affiliated regions	Per paper	1.21 (0.35)	1.35 (0.31)	1.24 (0.32)	1.22 (0.35)	*	.024		.974	**	.008	0.027		.878
	′	Total	3.12 (1.74)	3.64 (2.67)	2.85 (2.11)	3.45 (3.26)		.192		.235		.252	-0.242		.481
Publication Productivity Indicator	No. of research papers	Total	19.7 (19.6)	17.6 (19.0)	18.1 (16.9)	18.5 (16.2)		.228		.739		.383	-0.859		.510

Notes: $N=33$ (PIs). $^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$. S.D.=standard deviation.

the CNBI group and the control group during the project period, the CNBI group was found to have a significantly higher number of citations. In other words, CNBI has some positive effects on two of the paper productivity and impact indicators, the number of research papers and the number of citations. Thus, since no significant difference was detected between the CNBI and control groups when the total numbers of citations were compared, it is suggested that CNBI promoted a quantitative change of research papers, though there may have been no discernible effect on the quality of each publication.

In contrast to CNBI, iCeMS is ongoing, and our findings are only indicative. Three years of data from 2008 to 2010 were used for analysis, and a period of the same length was set as a comparison control for analysis (Table 4). Among Interdisciplinarity Indicators, no significant difference was seen either over time or in comparison to the control group in terms of HHI (Interdisciplinarity Index in Table 4). In contrast, the number of joint papers, affiliated organizations, and affiliated regions were found to be significantly increased over time and as compared to the control group. With regard to the number of research papers, no significant difference was detected comparing the pre- and post-start project periods, or with the control group. It is too early to consider the impact on citations.

4.5. Expert review on the KPIs

In order to assess the validity of KPIs and to identify key management actions contributing to the change in KPIs, an expert review was conducted on the obtained results shown in Tables 3 and 4. Interview comments regarding the impressions on measured KPIs and the key management actions of the interdisciplinarity projects were extracted and summarized (Table 5). According to those who managed each project, obtained KPIs were largely consistent with their impressions and evaluations on the outcome of the research projects. As for the key management actions, all the reviewers emphasized the importance of their annual research camp with active participation from all the researchers. While the management of iCeMS expressed a dramatic effect from recruiting foreign researchers on the expansion of internationality, CNBI management prioritized the positive effect of shared equipment room on the unity of CNBI researchers. As shown here, measured quantitative KPIs and their implications for the management policies of each project could be verified through a series of qualitative reviews.

5. Discussion

The (co-)creation of new research fields by interdisciplinary collaborative research, facilitated by a mentality of open innovation, is a global trend in which Japan is playing a central part. In this research, a theoretical framework and KPIs for measuring interdisciplinarity were developed, and their robustness was verified based on two separate research institutes within Japan. As a result, we have succeeded in observing how political goals set by the government are reflected in the strategy of the research institute and how management efforts at such institutions can lead to material changes in relevant KPIs.

In this section, three issues, (i) the significance of introducing new KPIs, (ii) the implications for research strategy, and (iii) future organizational activities will be discussed, based on observed results. It is envisioned that as co-creation evolves, it will deepen public-private collaborations on a global scale, to which the KPIs developed here will have greater relevance in an operational/benchmarking regime, which today is more common to commercial management.

5.1. Introduction of new KPIs

This research has demonstrated how multi-dimensional KPIs can measure and evaluate research project outcomes. Specifically, how, in addition to such Publication Productivity Indicators as the quantity of paper published, Interdisciplinarity Indicators—such as the degree of interdisciplinary collaboration (HHI), the degree of institutional collaboration (the number of affiliated organizations per paper), and the degree of international collaboration (the number of regions per paper)—have been newly defined and incorporated.

From an empirical perspective, three indicators of the degree of interdisciplinary collaboration, the degree of institutional collaboration, and the degree of international collaboration were additionally introduced, and the performances of actual research institutions were measured. When the results of the CNBI case for paper productivity were verified, a significant increase in the

Table 5
Expert review on key management actions and resulting KPIs.

	Center for NanoBio Integration (CNBI)	Institute for Integrated Cell-Material Sciences (iCeMS)
Reviewers	Project leader A management member (PI)	Project leader A management member (PI)
Impression on KPIs	KPIs are accurately reflecting the achievements of CNBI.	Measured KPIs are in a good accordance with the outcome of the actual activities of iCeMS.
HHI and joint papers	As expressed in the # of Joint papers before CNBI, it was true that open-minded researchers with a broader research network participated since its establishment	All the outcomes of collaboration between iCeMS researchers was not published so far, resulting in little response of HHI
Affiliated organizations	Increase in affiliated organizations would be driven mainly by the collaboration between researchers of different departments inside the University	Despite their integration into iCeMS, the researchers, with their single new affiliation, have demonstrated an expansion in the number of affiliations through their external research networks
Affiliated regions	Due to the lower priority on international collaboration of CNBI, increase in affiliated regions was not observed	Consistent with the obtained result, international research network of iCeMS is expanding steadily.
Key management actions contributing to KPIs improvement	Annual research camps with participation of all researchers were effective for achieving mutual understanding and establishing groundwork for collaborative researches	Annual research camps were very effective for facilitating internal communication between researchers
	Shared equipment room played an essential role for promoting communication between researchers and fostering a sense of unity of CNBI	Active recruitment of foreign faculty members was a key for expanding the internationality of iCeMS
	Organizational design (i.e., create 3 groups) based on the product-oriented perspective was a key for productivity enhancement	Employment of ''iCeMS Kyoto Fellows'', young PIs who can drive research projects through collaboration with multiple and different disciplines

number of research papers was observed when the pre- and post-start periods of project were compared. This suggests that organizational research activity at CNBI had a positive effect at least on the quality of research papers. These results showed good consistency with a separate qualitative evaluation of the effect on interdisciplinarity by questionnaire surveillance over the affiliated researchers (unpublished data) and the result of expert review (Table 5). This suggests that the evaluations of degrees of collaboration could be quantitatively measured by the method employed in this research utilizing a widely accessible paper database, similar to the evaluation of quantity or quality of research (Hall et al., 2001).

Evaluation of interdisciplinarity was previously dependent on the qualitative judgment of peer review of the collaborative activities, while scientific approaches to quantifying those degrees have been discussed recently (Abramo et al., 2009; Kajikawa and Mori, 2009; Porter et al., 2006, 2007, 2010; Rafols and Meyer, 2010). The validity of the quantitative approach employed in this research also suggests that two advantages can be added to such traditional methods as peer review. First, while it is difficult to perform peer reviews owing to its operational issues, a survey of interdisciplinarity by these bibliometric approaches can provide a substantial fact base and further analysis on the level and diversity of the interdisciplinarity of the project. Second, while peer review involves bias due to the personnel selection of reviewers or difficulty in comparative evaluation between different projects, this bibliometric survey can be reproducible and the calculated index reflecting the interdisciplinarity of the project can be compared between projects. Of particular note is the ability to make an observation in the organizational context which, we hypothesize, will increase in tangible significance as collaborative, interdisciplinary research initiatives make more deliberate attempts to break the mold of historical practice. For example, in the context of social deployment, where the purpose is to translate innovative science and accelerate time to market, public and private constituencies will need to be represented, with their different agendas and time frames. Such a context demonstrates the need for more than the mere fueling of innovation in the interdisciplinary sciences.

Common issues remaining in measuring interdisciplinarity arise from the fact that it totally depends on the publication database and its classification of subject categories. Classification of journals into research fields does not explicitly reflect the contents of articles themselves and may, therefore, in itself cause a disconnect with the actual research fields. In addition, publication databases do not comprehensively cover all types of publications, e.g., books and regional non-English journals (Wagner et al., 2011). Development of more universal paper classification, or using the keywords of each article would address both issues. In fact, Porter et al. (2010) attempted to categorize papers not listed in the database by their title. Kajikawa and Mori (2009) analyzed interdisciplinarity with the citation network instead of research field categorization. However, at the same time, the robustness of the index and the feasibility of implementation at the institutional level could be a necessary trade-off. Robust keyword and network analysis or simple evaluation with classified research fields could be used alternatively, depending on specific objectives. However, even though we took a simplified approach to using research categories for our analysis, measured interdisciplinarity was in good accordance with the impressions from the management of the research projects on these constructs.

Thus, the new and simple KPIs introduced above provide objective evaluation indicators that may be used as an adjunct to—or that, in time, a basis to replace traditional approaches.

5.2. Implications for research strategy

As described in Section 4, clear strategic goals are set at both a macro-policy level and at the institutional level. For the strategic management of interdisciplinary research institutions, it is evident that goal setting and clear planning/implementation of activities drive efficiencies in both institutional collaboration and/or interdisciplinary collaboration. Therefore, the planning of research strategy is materially important.

Although CNBI and iCeMS are both interdisciplinary research institutes, some differences showed in the observed trends of KPIs. Further work should be undertaken to assess the consistent patterns and to build a benchmark capability for refining predictive goal setting. When compared to the control groups for CNBI and iCeMS, significant increases in the three parameters of the Interdisciplinarity Indicators and in the number of joint papers were observed at CNBI, whereas at iCeMS, the number of affiliated organizations and the number of affiliated regions were found to be significant (Tables 3 and 4). These differences are thought to be a function of the differences in strategic intentions at the two research institutes. CNBI is an institute for generation-type projects, but no new department was established within the university and researchers participated in cross-departmental projects while still affiliated to existing departments. On the other hand, iCeMS is explicitly intended to form a new institute, and researchers transfer from existing departments to perform their research there, expanding international research activities. Hence, organizational design, the process of formation, and progress can and should be monitored by such analyses.

The most important factor for institutional strategy at CNBI is collaboration between different departments inside the university. For example, the promotion of collaborative research between the departments of engineering and medicine was a highly prioritized initiative of CNBI management. Since these collaborative research outcomes are typically published through joint authorship, this heightened collaboration is also directly reflected in the number of joint papers. Consistent with this, the number of presentations on the result of collaborative research among CNBI researchers at academic societies increased from 3 in FY 2005 to 25 in FY 2009 (unpublished data). Meanwhile, the central objectives of the first two years after the establishment of iCeMS included interdisciplinary collaboration within the institute, as well as the promotion of institutional collaborations with research institutions outside the university, especially outside Japan. However, as shown in the previous section, HHI has not increased between the pre- and post-start periods of iCeMS, while the number of research papers from other regions and other institutions has significantly increased. In addition, the number of joint papers among iCeMS researchers increased significantly, though it was still less than one publication per year per researcher. This is thought to be the positive result of a strategic initiative at iCeMS, which focused on reinforcement of internationalization among the missions of the WPI Program. Foreign researchers and research institutions were preferentially selected as collaborative research partners (referenced from interviews with iCeMS researchers). Continuous effort needs to be made to increase the extensity of research fields by leveraging the already increasing extensity of research networks.

We then conducted a correlation analysis between the Interdisciplinarity Indicators and the Publication Productivity Indicator. In the case of CNBI, a significant correlation was seen between the ratio of joint papers among total publications and the total number of publications, and between the number of affiliated regions per paper and the total number of publications (Supplemental Table 1). On the other hand, in the case of iCeMS, a significant correlation was observed only between the

Interdisciplinarity Index and the total number of publications (Supplemental Table 2). Although the causation needs deeper probing, it was suggested that the researchers at CNBI place more emphasis on publishing joint papers, whereas the researchers at iCeMS try to expand their research fields.

From the above discussion, the KPIs introduced in this research are thought to be useful not only for tracking the progress of research outcomes, but also for deciding the orientation of research institutions themselves.

5.3. Implications for organizational activities and management

The results obtained from the KPI survey provide objective information for post-project evaluation by the government sponsor, as well as for the daily management of the research institute. Publication is the outcome of the research activity by researchers and the managerial efforts to promote integration and research. In contrast to the traditional peer review on a timely basis, publication indicators can be measured quantitatively and are reproducible, and could thus play a complementary role to the peer review. Although the publication is a lagging indicator to the actual activities of the research projects, it is possible to perform measurements with some of the KPIs, for example, the number of research papers or the number of joint papers during the project period. Significantly, periodic data acquisition from affiliated researchers as well as understanding the current situation and discussing improvement plans during institute management decision making on these indicators can be implemented. For example, initiating a PDCA (plan-do-check-action) cycle of R&D activity could readily contribute toward a systematic and continuous improvement of processes and activities, especially in applied research and/or interdisciplinary research in which multiple researchers from different institutions or academic fields are participating. From a manufacturing perspective, this has clear parallels with the notion of Kaizen.

Research project management by using the number of research paper indicator or an Interdisciplinarity Index has already been proposed (Bonnevie-Nebelong, 2006; Kao and Pao, 2009; Porter et al., 2010). As shown here, combining Interdisciplinarity Indicators, including the extensity of the research network—e.g., the number of joint papers, affiliated organizations, and affiliated regions—in addition to HHI for each researcher or for the entire institute will allow for a more holistic evaluation. Such an approach is expected to lead to a more accurate preparation and implementation of an institution's management strategy.

The number of citations is often employed as an outcome indicator. However, opinions differ on the timing of exploiting this indicator (Garrett-Jones and Aylward, 2000). This indicator is positioned as an important outcome indicator when considering the quality of research output, but variations may occur, depending on when the analysis is performed, and it thus needs careful interpretation.

Typically, at interdisciplinary research institutes, including CNBI and iCeMS, the overt promotion of collaboration between researchers from different fields is organizationally attempted by various approaches, such as organization of research camps in which all researchers are required to participate, hosting of periodical seminars or symposiums, and the installation of shared equipment rooms. In this paper, we have investigated the relationship between management actions and KPIs through expert reviews. In order to verify which of these approaches is more effective in cross-field collaboration or generation of outcome and to obtain best practice guidelines for institute management, it will be necessary to broaden the data collection. For example, future analysis might attempt to establish a link between frequency of participation in the events set by the institute, and the Publication Productivity or Interdisciplinarity Indicators of each individual. In addition, consideration of the communication process between researchers during the formation of collaborative research will be necessary for obtaining detailed suggestions for researchers. This will be especially interesting amongst researchers for whom English is not their first language and cross-border interaction needs enhanced encouragement.

6. Future perspectives

The foregoing has illustrated a flexible framework in which, with more detailed data, hypotheses can be refined and tested recursively for ultimate identification of scalable and transferable indicators that drive research improvement, across any dimensions. However, looking to the future it is necessary to be clear about the limitations of this embryonic research.

6.1. Expansion of investigation targets and institutes

In this survey, only PIs (or their equivalent respondents) at CNBI and iCeMS were targeted for analysis. However, many junior researchers and candidates, such as postdoctoral or senior PhD students, are also involved, and we have not been able to evaluate their contributions. We plan to expand the target of analysis to all affiliated researchers. Moreover, concerning the quantitative and qualitative survey results obtained, efforts will be made to derive an accurate understanding of behavior patterns desired for promotion of integration and collaborative research by means of periodical comparison and verification between research institutions, job classifications, fields, and research groups, and by regular KPI tracking.

Furthermore, in order to enhance the versatility of the management framework and KPIs proposed in this survey, the investigation target should be expanded in the future, within and between institutions. It would be natural to expand to the accepted institutes in the WPI Program (a total of six institutes) and of the FIRST Program (total of 30 institutes). Surveys could also be broadened to similar research institutions outside of Japan to ensure global consistency and coherence.

6.2. Improvement of KPI

Although this research observed and evaluated academic outcomes based on research paper productivity, academic outcomes and impacts are not limited to research papers. In particular, there is no doubt that invention of patents, which are the seeds of technology; creation of venture enterprises originating from universities; and distribution of products and services, which are the true benefits for end users, are essential evaluation indicators when discussing innovation originating from universities. Beyond these market influences there will naturally be pedagogic benefits that can enhance future university research, teaching and curriculum development.

Of more immediate attention, with greater public-private collaboration envisaged, are the management activities of such research projects. With this analysis, universities and public research institutions with requirements for promoting industry–academia collaborative activity will need to consider a broader, and perhaps, somewhat contradictory, set of objectives. In this context, we suggest that an empirical analysis on the "hybrid" university spin-offs should be implemented to establish and measure a broader range of evaluation criteria and to determine whether these activities holistically meet differing commercial and social needs.

6.3. Demonstration of KPI in research management

One of the key achievements of this research was to establish a theoretical framework and KPIs for interdisciplinary research institutes and their projects. However, due to a lack of data on the actual activity and behavior of each researcher, it might be difficult to discuss the possibility of applying existing project management approaches to interdisciplinary research projects. In order to enhance the existing framework to explicitly incorporate project management capabilities specific to interdisciplinary projects, a more detailed analysis from the perspective of the communication process and of short-term interaction between all levels of researchers would be necessary.

7. Conclusion

In this study, the empirical analysis and verification of an evaluation framework with KPIs was carried out on two different research institutes for interdisciplinary and collaborative research. The study explicitly included the evaluation of research projects by introducing Interdisciplinarity Indicators and a Publication Productivity Indicator. We have successfully observed both consistencies and inconsistencies among governmental funding strategies, the management policy of each institute, and their outcomes as measured by KPIs, in terms of these two indicators. As stated at the outset, the reinforcement of academic R&D management and the development of a management system are essential for driving effectiveness and efficiencies in present-day universities and public research institutions. In the future, a detailed understanding of the impact of the rules or goals specific to academic organizations, together with pilot studies trying to establish a generalizable and scalable framework as a management system for academic projects, will be a greater priority.

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Appendix A. Supplementary information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.technovation.2011.12.003.

References

Abramo, G., D'Angelo, C.A., Caprasecca, A., 2009. Allocative efficiency in public research funding: can bibliometrics help? Research Policy 38, 206–215.

Bartlett, C.A., Ghoshal, S., 1998. Managing Across Borders: The Transnational Solution. Harvard Business Press, Cambridge, MA.

Boardman, P., Corley, E., 2008. University research centers and the composition of research collaborations. Research Policy 37, 900–913.

Bonnevie-Nebelong, E., 2006. Methods for journal evaluation: journal citation identity, journal citation image and internationalisation. Scientometrics 66, 411–424.

Bozeman, B., Boardman, C., 2003. Managing the New, Multipurpose, Multidiscipline University Research Centers: Institutional Innovation in the Academic Community. IBM Endowment for the Business of Government, Washington D. C.

Bozeman, B., Boardman, C., 2005. The NSF engineering research centers and the university–industry research revolution: a brief history featuring an interview with Erich Bloch. Journal of Technology Transfer 29, 365–375.

Chesbrough, H., 2003. Open Innovation: The New Imperative for Creating and Profiling from Technology. Harvard Business Press, Cambridge: MA.

Cohen, W.M., Nelson, R.R., Walsh, J.P., 2000. Protecting their intellectual assets: Appropriability Conditions and Why U. S. Manufacturing Firms Patent (or not), NBER Working Paper 7552.

Committee on Facilitating Interdisciplinary Research, National Academy of Sciences, National Academy of Engineering, Institute of Medicine, 2004. Facilitating Interdisciplinary Research. National Academies Press, Washington D. C.

CORDIS, 2011. URL 〈http://cordis.europa.eu/fp7/home_en.html〉 (accessed 23. 3. 2011).

Corley, E., Boardman, P., Bozeman, B., 2006. Design and the management of multi-institutional research collaborations: theoretical implications from two case studies. Research Policy 35, 975–993.

Etzkowitz, H., Kemelgor, C., 1998. The role of research centres in the collectivization of academic science. Minerva 36, 271–288.

EUREKA, 2011. URL: 〈http://www.eurekanetwork.org/〉 (accessed 23. 3. 2011).

EUROSTAT, 2001. URL: 〈http://epp.eurostat.ec.europa.eu/portal/page/portal/microdata/cis〉 (accessed 23. 3. 2011).

Garrett-Jones, S., Aylward, D., 2000. Some recent developments in the evaluation of university research outcomes in the United Kingdom. Research Evaluation 9, 69–75.

Hage, J.T., 1999. Organizational innovation and organizational change. Annual Review of Sociology 25, 597–622.

Hage, J.T., Hollingsworth, R., 2000. A strategy for analysis of idea innovation networks and institutions. Organization Studies 21, 971–1004.

Hage, J., Mote, J., 2008. Transformational organizations and institutional change: the case of the Institut Pasteur and French science. Socio-Economic Review 6 (2), 313–336.

Heinze, T., Shapira, P., Rogers, J.D., Senker, J.M., 2009. Organizational and institutional influences on creativity in scientific research. Research Policy 38, 610–623.

Hall, B., Jaffe, A., Trajtenberg, M., 2001. The NBER patent citations data file: Lessons, Insights and Methodological Tools, CEPR Discussion Paper No. 3094.

Haythornthwaite, C., 2006. Learning and knowledge networks in interdisciplinary collaborations. Journal of American Society of Information Science and Technology 57 (8), 1079–1092.

J-NIS, 2003. URL: 〈http://www.nistep.go.jp/nistep/about/thema/thema2-e.html〉 (accessed 23. 3. 2011).

Jordan, G.B., 2006. Factors influencing advances in basic and applied research: variation due to diversity in research profiles. In: Hage, J., Meeus, M. (Eds.), Innovation, Science, and Institutional Change: A Handbook of Research. Oxford University Press, New York, pp. 173–195.

JST, 2006. URL: 〈http://www.jst.go.jp/keytech/03nano/pd.html〉 (accessed 23. 3. 2011).

Kao, C., Pao, H.L., 2009. An evaluation of research performance in management of 168 Taiwan Universities. Scientometrics 78 (2), 261–277.

Kajikawa, Y., Mori, J., 2009. Interdisciplinary research detection by citation indicators, Proceedings of the 2009 IEEE IEEM.

Klein, J.T., Porter, A.L., 1990. Preconditions for interdisciplinary research. In: Birnbaum-More, P.H., Rossini, F.A., Baldwin, D.R. (Eds.), International Research Management. Oxford University Press, New York, pp. 11–19.

Kocaoglu, D.F., 1994. Technology management: educational trends. IEEE Transactions on Engineering Management 41 (4), 347–349.

Kotnour, T.G., Farr, J., 2005. Engineering management: past, present, future. Engineering Management Journal 17 (1), 15–26.

Kuhn, T.S., 1962. The Structure of Scientific Revolutions. Univ. of Chicago Press, Chicago.

Lee, M.J., 2005. Micro-econometrics for Policy, Program, and Treatment Effects. Oxford University Press, New York.

Levin, R.C., Klevorick, A.K., Nelson, R.R., Winter, S.G., 1987. Appropriating the returns from industrial research and development. Brookings Papers on Economic Activity 3, 783–820.

Oba, J., 2008. Creating world-class universities in Japan: policy and initiatives. Policy Futures in Education 6 (5), 629–640.

Porter, A., Cohen, A., Roessner, D., Perreault, M., 2007. Measuring researcher interdisciplinarity. Scientometrics 72 (1), 117–147.

Porter, A.L., Roessner, J.D., Cohen, A.S., Perreault, M., 2006. Interdisciplinary research: meaning, metrics and nurture. Research Evaluation 15, 187–195.

Porter, A.L., Schoeneck, D.J., Roessner, D., Garner, J., 2010. Practical research proposal and publication profiling. Research Evaluation 19 (1), 29–44.

Rafols, I., Meyer, M., 2010. Diversity and network coherence as indicators of interdisciplinarity: case studies in bio-nanoscience. Scientometrics 82 (2), 263–287.
SCJ, 2008. URL: 〈http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-20-t51-3e.pdf〉 (accessed 23. 3. 2011).
Scopus, 2011. URL: 〈http://www.scopus.com/source/browse.url?zone=TopNavBar&origin=journalEvalPage〉 (accessed 23. 3. 2011).
Shenhar, A.J., 1998. From theory to practice: toward a typology of project-management styles. IEEE Transactions on Engineering Management 45 (1), 33–48.
Shenhar, A.J., 2001. One size does not fit all projects: exploring classical contingency domains. Management Science 47 (3), 394–414.
Stahler, G.J., Tash, W.R., 1994. Centers and institutes in the research university: issues, problems, and prospects. The Journal of Higher Education 65, 540–554.
Stirling, A., 2007. A general framework for analysing diversity in science, technology and society. Journal of the Royal Society Interface 4, 707–719.
Tao, J., Daniele, J., Hummel, E., Goldheim, D., Slowinski, G., 2005. Developing an effective strategy for managing intellectual assets. Research Technology Management 48 (1), 50–58.
The Prime Minister of Japan, 2008. National Guidelines for Evaluating Government Funded R&D. URL: 〈http://www8.cao.go.jp/cstp/english/doc/h20_nationalglfor_eval_gov_funded_rd.pdf#page=4〉 (accessed 23. 3. 2011).
Wagner, C.S., Roessner, J.D., Bobb, K., Klein, J.T., Boyack, K.W., Keyton, J., Rafols, I., Borner, K., 2011. Approaches to understanding and measuring interdisciplinary scientific research (IDR): a review of the literature. Journal of Informetrics 5 (1), 14–26.

Dr. Tomohiro Anzai is a Project Associate Professor of the Translational Research Initiative, Global COE program, and Nanobio FIRST Program at the University of Tokyo. He also serves as a manager of Fast Track Initiative, Inc., an independent venture capital firm in Japan. Dr. Anzai started his professional career as a management consultant at Arthur D. Little (Japan), Inc., serving biotech, diagnostics, and healthcare companies. He received his PhD in molecular biology from the University of Tokyo, Graduate School of Frontier Sciences in 2004. His research interests include innovation management of academic research projects and industry–academia collaboration.

Mr. Ryoichi Kusama is a PhD student in the Department of Mechanical Engineering and Science, the Graduate School of Engineering, Kyoto University. He received his BS and MS degrees from Kyoto University, Japan, in 2008 and 2011, respectively. His research interests include innovation management, knowledge management, and organization theory.

Dr. Hiroyuki Kodama is a Research Associate at the Institute for Integrated Cell-Material Sciences (WPI-iCeMS), Kyoto University. In the Innovation Management Group at iCeMS, he is in charge of facilitating industry-academia collaborations, international research alliances, and interdisciplinary research collaborations. He earned a PhD degree in Molecular Biology from the University of Tokyo. He has worked at McKinsey & Company, Inc., Japan, in marketing and operations management in the healthcare and retail industries.

Dr. Shintaro Sengoku is an Associate Professor of the Institute for Integrated Cell-Material Sciences (WPI-iCeMS), Kyoto University, where he leads the Innovation Management Group. He earned a BS from the University of Tokyo and received his PhD in molecular biology from the Graduate School of Science at the University of Tokyo. He previously worked at McKinsey & Company, Inc., a venture capital company, and at the Graduate School of Pharmaceutical Sciences of the University of Tokyo as a senior lecturer. His specialties are knowledge, project and organization management for interdisciplinary research and fusion sciences, and innovations in the field of stem cells and related science and technology.