T2R2 東京工業大学リサーチリポジトリ
Tokyo Tech Research Repository

論文 / 著書情報
Article / Book Information

Title	Managing Academic Interdisciplinary Research towards Innovation: A Resource and Communication-Based Approach
Authors	Tomohiro Anzai, Shintaro Sengoku
Citation	Technology Transfer and Entrepreneurship, Vol. 3, No. 2, pp. 70-81
Pub. date	2016, 9
DOI	http://dx.doi.org/10.2174/2213809903666160419104146
Note	This file is author (final) version.

Powered by T2R2 (Tokyo Institute Research Repository)

Managing Academic Interdisciplinary Research towards Innovation: A Resource and Communication-Based Approach

Tomohiro Anzai[a], Shintaro Sengoku[*b]

[a]*Translational Research Initiative, the University of Tokyo, Tokyo, Japan;* [b]*Graduate School of Innovation Management, Tokyo Institute of Technology, Tokyo, Japan*

Abstract: Academic research projects aimed at integrating interdisciplinary research fields are being implemented at universities and research institutions. The present study focuses on action-based research through two examples of academic interdisciplinary research projects, with the objective of observing institutional activities and validating their effectiveness. First, we generated a managerial framework for institutional activities from the perspective of resource and communication management. Then we conducted a set of surveillances in these two projects to understand the researcher's activity of each project. Based on these facts, we tried to identify effective factors for the promotion of interdisciplinary research projects through: (i) descriptive statistical analyses across research institutions on the preference of communication partners, communication element and organisational complementation and the transaction of resources and organisation process, and (ii) cause-effect analyses on the performance of communication opportunities and the preference of communication management, setting a bibliometric interdisciplinary index to a dependent variable. The analytical approach we have proposed in this study could help to rationalise the management of academic interdisciplinary research projects. Further, it could also be applied widely to project management and to benchmarking and evaluation of the academic research project.

Keywords: project management; program management; interdisciplinary research; research administration; science and technology policy; collaboration.

[*]Address correspondence to this author at the Graduate School of Innovation Management, Tokyo Institute of Technology, P.O. Box: W9-114, Tokyo, Japan; Tel/Fax: +81-3-5734-3571; E-mail: sengoku.s.aa@m.titech.ac.jp

1. INTRODUCTION

1.1. Current context in interdisciplinary research

The policies in the fields of science and technology currently emphasise the importance of promoting interdisciplinary research (IDR). IDR is defined 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 specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice [1].

Many universities and public research institutions are considering numerous organisational approaches for IDR [2]; partly because science is under pressure to become more relevant to society [3]. Currently, IDR is widely recognised as a scientific path towards scientific breakthroughs and as a means to promote innovation [4,5]. Previous efforts towards promoting IDR have highlighted the importance of reinforcing policies and garnering support from the public sector, implementing autonomous management in research institutes, and training key researchers with a broader prospective. Simultaneously, methodologies and pitfalls for evaluating IDR have been investigated in the context of policy research [6-8].

Recently, government policies have encouraged public funding programmes for scientific projects in which the promotion of interdisciplinary collaboration was set as one of their primary missions. On the other hand, the management of an IDR institute has been left to an individual or a project leader, even though the establishment of managerial practices is important [9,10]. Training of key researchers has been recognised in scientific societies as an area of meritocracy; however, more systemic approaches are now required to address the recent need to diversify the career paths of researchers [11].

The present study explores the different ways to adopt organisation management at research institutes and to effectively promote IDR. Specifically, case examples at two research institutes are analysed for determining the types of interaction between researchers that lead to the promotion of IDR based on an activity index obtained from surveys. In addition, the type of policy that promotes/restrains IDR is analysed based on the activity index and a performance index that is obtained from publication information. Further, based on the results of these analyses, the management framework for IDR projects at research institutes is proposed.

IDR entails interactions between researchers who have a different sense of value or knowledge. In particular, the interaction at the generation stage of IDR projects is non-stationary compared with research projects that are closed to one field (or mono-disciplinary research). The appropriate management style thereof is thought to have a substantial effect not only on the start of research projects but also on the productivity after implementation. Accordingly, a detailed observation and analysis of the interactions in the generation process of IDR is thought to be of great significance.

1.2. Research background

In this section, we examine three approaches that have been associated with the management of IDR to explore a fusion for a managerial framework. The results obtained will be analysed from the academic research perspective, and practical tools will be identified for research institutes or researchers to conduct IDR. Thus, this study covers the approaches of scientometrics, organisation management, and technology management. These three approaches have been reviewed in light of previous case studies. The approach of this study has been described in the last section.

1.2.1. Scientometrics

In scientometric evaluation, studies that have employed patents and publication database have been actively carried out thus far. For example, the number of forward citations is mainly employed as the measurement index of the value of patents [12,13]. For example, a study surveyed patent inventors through questionnaires regarding their technical and economic importance [14]. It was shown that the number of forward citations of patents filed had a positive effect on the recognition of the technical and economic importance. The number of publications, such as articles, and the number of citations, such as successive articles, was used as the measurement index of the value of publications [6,15-19]. This is otherwise known as an indirect peer review, and is also recognised as an index that complements or replaces direct peer review by experts [20].

This study particularly focuses on the interdisciplinary index through case studies of research institutes of IDR. Measures to quantitatively and objectively evaluate the degree of interdisciplinary collaborations have been demonstrated [6, 21-24]. For instance, a previous study tried to evaluate interdisciplinary performance by using three indicators: ‘variety’ (the number of academic disciplines), ‘balance’ (the evenness of the distribution of disciplines), and ‘disparity or similarity’ (the degree of difference between disciplines) [6]. Such metrics for interdisciplinary performance have recently been employed to evaluate the strategic fitness and effectiveness of funded research projects with the purpose of promoting IDR [9].

1.2.2. Organisation management

Investigative research related to research and development activities of corporations prominently use surveys, such as the Yale Survey I/II of the United States and the CIS survey of Europe. However, comparative investigation at universities and public research institution levels, and organisation theory-based validation thereof is not very active, except for a few examples [7,9].

The critical points for evaluating the performance of universities and public research institutions is through the introduction and operation of key performance indicators

(KPI) and activity measures. Furthermore, from the management perspective, two important factors need to be fulfilled: that the evaluation system is designed based on on-site needs for effective evaluation of the result feedback, and that the system needs to be simple enough to be operable on-site [8].

This approach is also based on scientometrics and organisation management and has been empirically and thoroughly investigated through practices at research institutions. Although individual approach efforts have been actively implemented thus far at each research institution, common recognition for the style of management is far from being created. This is because of a lack of social scientific studies to generalise findings in individual practices into theories. Moreover, one of background factors is the sparse cooperation between researchers of the social sciences field who correspond to the development of such management system and researchers of natural sciences field who are practitioners.

One possible approach is focusing on key interactions in IDR projects. For instance, the process from the generation and completion of research projects can be investigated through detailed observations of researchers where a standard framework based on this measurement and evaluation generated in the process needs to be planned and presented. Specifically, the focus is placed on transactions within or outside organisations and the communication interface [25,26].

1.2.3. Project Management

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 organisational change for interdisciplinary research have been explored [5,27,28]. The case analysis of the creation of a new discipline of biomedicine at a French research institution noted that the development of carrier paths in new interdisciplinary fields enabled the institution to integrate two disciplines [28]. It is also articulated the organisational factors that influence the creativity of organisational research activities by analysing 20 case studies of prize-winners [29]. Another study 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 organisation for a new discipline, and further defined the requirements to be fulfilled at each stage [2]. 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 organisational complexity—i.e., variety of disciplines [30,31]

Another research avenue has been to describe individual behaviour at institutions with a collaborative process. A comparative analysis of behaviour patterns such as daily usage of time across 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 [32]. 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 behaviour at the individual researcher level. Another study verified what kind of benefits researchers themselves expect in collaboration between cross-field researchers [33]. 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 emphasised. 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.

1.3. The approach of the present study

In this study, KAIs were newly applied to activities that were important for the operation of research institutes (in addition to KPIs). The conceptual diagram is shown in Figure 1. To validate this framework, two interdisciplinary research institutes in Japan that acknowledge the promotion of IDR were investigated as empirical study cases.

Items for investigation/analysis are shown in Table 1. The six points that should be validated through comparison/analysis of survey results are: (i) the preference of communication partners, (ii) the importance of communication opportunities and the degree of organisational complementation, (iii) the importance of resources and the outcome of organisational approach, (iv) the preference of communication partners and the method of organisational correspondence, (v) the preference of communication opportunities in the interdisciplinary performance connection/presentation process, and (iv) the preference of communication management method as key activity indicators (hereinafter 'KAIs'). Based on these points, evaluation and implication of the analysis result, future prospects, as well as the limitations of this study and future approaches were discussed.

The Introduction section should include the background and aims of the research in a comprehensive manner, for the researchers.

2. MATERIALS AND METHOD

In this section, the details of the approach (already described in the previous section) will be explained.

2.1. Survey design

For the survey design, the theoretical model of transaction management was employed to help configure the three analytic viewpoints of transaction partners, transaction resources and communication opportunities [25,26]. The five-step Likert Scale was employed as the evaluation scale. Faculty members affiliated with Kyoto University, the Institute for Integrated Cell-Material Sciences (WPI-iCeMS, N = 33, the number of PI = 17), and researchers affiliated with the University of Tokyo, Center for NanoBio Integration (CNBI, N = 114, the number of PI = 35) were the investigation targets in this study. A total of 88 record

samples were obtained as a result of an investigation through questionnaires, including 60 samples from CNBI (the number of PI = 27) and 28 samples from WPI-iCeMS (the number of PI = 15). These samples, excluding the ones with incomplete answers, were subjected to subsequent analysis. These three viewpoints were integrated: (i) comparison between the two research institutes of WPI-iCeMS and CNBI, (ii) comparison between the PI and non-PI classes at WPI-iCeMS, and (iii) comparison between the research fields of biology and chemistry/physics at WPI-iCeMS. A T-test was performed for the significant difference of scores of explanatory variables rendered by the rank scale, and the impact of each variable was estimated.

2.2. Definition of interdisciplinary index

To evaluate the interdisciplinary performance of each researcher, the following formula for the diversity evaluation of patents of corporations [34] was employed and the interdisciplinary index for each researcher was defined. This index ranges from 0 to 1 and a value closer to 1 indicates that the published articles corresponding to the research fields are diverse.

This investigation is based on publications included in the database of SciVerse Scopus (Elsevier B.V.) Each publication can be classified into 26 major research fields and sublevel classifications thereof rendered by Scopus. The specific method was as follows: based on the list of published articles for each researcher created from Scopus, the identity of each researcher was verified, and an interdisciplinary index was calculated from the amended list. Thus, the interdisciplinary index was set as the explained variable, and variables that differed between the above-described three groups were selected from the significantly correlated explanatory variable groups to create a linear multiple regression model. The relationship of each impact factor was analysed, and the characteristics of researchers with high interdisciplinary performance were extracted.

This section provides details of the methodology used along with information on any previous efforts with corresponding references. Any details for further modifications and research should be included.

3. RESULTS

In this section, case examples at the two research institutes of CNBI and WPI-iCeMS are integrated to develop a managerial framework. CNBI's primary objective is to promote collaboration between departments inside the University of Tokyo, in particular 'medicines-engineering collaboration'. WPI-iCeMS' central aim is to promote cooperation between Kyoto University and internal and external research institutions, in particular 'international collaboration'. CNBI has completed a five-year project in March 2010, and WPI-iCeMS has completed the first term of a project in June 2012. A brief overview of these two research institutions is summarised in Table 2.

3.1. Descriptive statistics

This section shows the result of investigation of KAIs at the two research institutes and the result of comparison between the two institutions. All of the semi-quantitative evaluations employed the five-point Likert Scale, which defines 1 as "not important at all" or "not sufficient at all" and 5 as "extremely important" or "completely sufficient" and 3 as neutral.

3.1.1. Preference of communication partners

Table 3 summarises the investigation results of primary preferences of communication partners in each phase of the IDR projects with researchers in different fields.

Consistently in each phase, from initialising to planning and then to executing/controlling, communication between principal investigators (PI) of the own group and the partner group was emphasised. This is a reasonable result considering that every PI is the chief of his/her research group and he/she has the responsibility to decide on the implementation of collaborative research projects, especially in the initialising phase when their experience and broad human network can be useful. On the other hand, it should be noted that researchers of the own and the partner groups were similarly emphasised to the PI. At least in research fields targeted by these case examples, it is suggested that a more diverse specialised knowledge or research methodology is necessary, and therefore recruitment of a relatively large number of researchers is desirable.

3.1.2. Importance of communication element and organisational complementation

Table 4 shows the investigation results of the importance of various elements for communication and the degree of complementation by each project in the planning phase of IDR projects.

The following eight items were set as key success factors of communication: (1) language skills (English proficiency in case of international communication); (2) physical distance (the distance between each other's research facilities or offices); (3) sense of values (consent of attitude or ethical views towards scientific research); (4) credibility (compliance on decided matters); (5) comprehension of significance (degree of commitment); (6) logicality (having a logical mind and consent of the discussion style); (7) research approach (understanding the research methodologies or techniques of each other's fields); and (8) specialised knowledge (understanding of expertise or technical terms of each other's fields).

The results of the investigation showed in Table 4 that researchers from both research institutes emphasised on credibility (having the highest interest), followed by comprehension of significance. This suggests that compliance on agreed matters and commitment are universally important for the smooth implementation of IDR projects. Two items with significant difference between the two institutions were language skills and physical distance. This difference is consistent with the difference in strategic policies of the two institutions, i.e. emphasising cooperation between other departments within the university at CNBI, and cooperation with other foreign universities as the primary policy at WPI-iCeMS.

Focusing next on the degree of organisational complementation for these factors, evaluation related to trust was the highest at both research institutes. This suggests the possibility that compliance on agreed matters, which could be

difficult at the level of individual researchers or research projects, became easier by organisationally implementing research project management. Another noteworthy matter is that both institutions placed a relatively high evaluation on the sense of values, particularly CNBI. Thus, it can be more appropriately construed that the attitude or ethical views towards scientific research, which sometimes differs between fields, can be eased or bridged by focusing on organisational policies, such as setting up conversation opportunities between researchers of different fields, rather than venturing into the sense of value of individual researchers.

3.1.3. Importance of the transaction of resources and organisation process

Table 5 shows the investigation results of the importance of resources and the degree of organisational complementation thereof in the implementation phase of IDR projects with researchers of different fields.

The following 13 items were set as classifications of transaction resources: (1) human resources - project leaders; (2) human resources - other researchers; (3) human resources - technicians and assistants; (4) physical assets such as space, instrument, equipment, or facility; (5) intangible assets such as database, experiment or know-how; (6) opportunities for information exchange; (7) funds - direct expenses; (8) funds - indirect expenses including personnel expenses; (9) authority to use the above-mentioned resources; (10) administrative tasks; (11) operational know-how such as project management skill; (12) brand such as appeal or power; and (13) platforms such as applicable research programmes or schemes.

An almost identical tendency was observed between the two research institutes. In other words, needs related to human resources (items 1, 2 and 3 above) were relatively high at both research institutes, and in particular, need for project leaders was the highest at both, implying that project leaders that lead the IDR on-site are scarce. The second highest were research funds (items 7 and 8 above) and the tendency to emphasise securing funds for direct expenses. This suggests an issue in acquiring research funds, which tend to lack a specialised understanding of each field than single field researches, owing to the existence or scope of two or more target fields while implementing IDR. Further, needs of physical assets such as space and instrument, equipment or facility for IDR, was also highly evaluated.

According to the answers for the organisational complementation, opportunities for information exchange gained the highest evaluation. The evaluation of the high-needs items were human resources (other researchers), funds (direct expenses), and physical assets. However, investigation results were lower than 4.0 for almost all items. This suggests that devising organisational support for IDR still has room for improvement.

3.2. Cause-effect analysis

Next we analysed what kind of management policy would promote IDR. We analysed the impact of KAIs (obtained from the survey) on KPIs (obtained based on the publication information). In this analysis, among the two case examples, we focused on WPI-iCeMS that has diverse communication opportunities with domestic and foreign research institutes in addition to opportunities within the institute and within universities.

Before analysis, evaluation of interdisciplinary performance for past publications for PIs or equivalent at WPI-iCeMS (N=28) was implemented by employing the method shown in the methods section. The result obtained was set as a KPI. On the other hand, management efforts that were addressed at both institutions were set as KAIs such as: (i) the impact of preference of communication opportunities on interdisciplinarity in the initialising phase of IDR projects and (ii) the impact of preference of communication management method on interdisciplinarity in the executing/controlling phase of IDR projects.

3.2.1. Impact of communication opportunities on the IDR performance

Two multiple regression models with an interdisciplinary performance set as the explained variable and survey results related to the usefulness and participation frequency of communication opportunities as each explanatory variables are shown in Table 6. Communication opportunities were opportunities normally performed in the observation case example, which were organised into six categories: (1) hosted international symposia; (2) faculty meetings; (3) other meetings or gatherings within the institute; (4) other meetings or gatherings within other departments; (5) academic conferences and symposiums; and (6) external committee.

Firstly, in an evaluation of usefulness, other meetings or gatherings within the institute and other meetings or gatherings within other departments had positive impacts ($p<0.05$ and $p<0.1$, respectively). On the other hand, looking at participation frequency, the former had a negative impact ($p<0.05$) and the latter did not have any significance. This means that 'other meetings and gatherings within the university' provides useful conference opportunities to initialise IDR projects, but reckless meetings/participation has an inhibitory influence. In other words, the result suggests that tactical planning and selection of communication opportunities is necessary.

With regards to participation frequency, 'hosted international symposia' and 'external committee' had positive impacts ($p<0.05$ and $p<0.01$, respectively). On the other hand, academic conferences and symposiums had a negative impact ($p<0.01$). International symposiums are held about 4-6 times a year at WPI-iCeMS. Each of these focuses on particular academic areas while setting themes that emphasise interdisciplinary prospects. Speakers from various fields are invited from within the research institution/university and outside the university. Although their usefulness is not always recognised by the parties involved, it is suggested that organisational planning and implementation of communication opportunities aimed for such inter-field interactions will become the basis for the generation of IDR projects. On the other hand, academic conferences and symposiums are often prone to be specialised in a single area. Consequently, the theory is that the participation in such opportunities or research projects generated therefrom results in the loss of generation opportunities of IDR projects.

3.2.2. Impact of communication management method on the IDR performance

The multiple regression model with an interdisciplinary performance set as the explained variable and survey results related to communication management method as each explanatory variable is shown in Table 7. Communication management were management methods normally performed in the observation case example, which were organised into 13 categories: (1) the conference and meeting is scheduled with sufficient leeway on time; (2) the agenda is specifically set and shared; (3) discussion materials are prepared beforehand and shared; (4) material of the other presenter is distributed at the meeting; (5) PI or representative is attending; (6) time and number of topics are appropriate; (7) the participants are earnest; (8) the participants are actively speaking out; (9) few conflicts in opinions; (10) the meetings are operated smoothly; (11) late arrival and early dismissal are allowed; (12) action items and future plans are clear after meetings; and (13) the meeting minutes are created and circulated after the meeting.

The results show that (2) and 4) had positive impacts on interdisciplinary performance (both $p<0.05$). All of these items were held before such communication opportunities, which means that the tactical setup and advance preparation are important (which gives similar suggestions as the previous section). On the other hand, (11) and (12) gave a negative although weak impact. These results need to be interpreted carefully, because the former is an action that needs to be avoided in ordinary meetings or discussions, whereas the latter needs to be encouraged. This may suggest that a degree of flexibility rather than constraints in meeting operations or ex-post consents will contribute to the creation of an atmosphere that will facilitate discussion of IDR possibility or realisation of ground-breaking ideas. Thus, it can be concluded that the essence of communication management for generation of IDR projects is prior consent, including getting across the objective or sharing of information.

4. DISCUSSION

4.1. Characteristics of the present study

Recently, innovation is defined as the creation of new social value that originates from breakthrough discoveries or innovative inventions produced through new combinations. Broad innovative changes in technology, human, organisation, and society are promoted in the process of innovation promotion. In this context, the IDR is widely currently recognised as one of promising approaches to create breakthrough scientific findings and/or disruptive technology through a fusion approach across different way of thinking, knowledge and talent mix. The analysis of the database on the article citation number in patents, i.e. science linkage, has been recently used as an objective evaluation approach of the impact of research activities, including basic research on innovation; trends thereof will be discussed later.

A noteworthy benefit of our study is its contribution to establishing a viewpoint to evaluate the transaction-based approach. As stated in the introductory section, communication avenues such as meetings and conferences, where researchers from various disciplines can interact and plan research projects, are vital for conducting IDR projects. This is because IDR projects require such interdisciplinary communication, unlike mono-disciplinary projects; therefore, all information should be presented with a high degree of clarity. In this respect, the IDR project management approach used in this study is the most effective and valid approach for facilitating suitable communication opportunities and environments. This approach is also ideal for optimising such communication opportunities to evaluate and determine the nature and manner of the distribution of research resources.

In the present study, we divided the task of optimising interaction or communication opportunities into the following four main elements: (i) the use of a multi-layer communication design that also includes non-PI (the 'who/whom' aspect) rather than a top-to-top approach, (ii) optimal design with respect to interaction frequency/location and physical aspects (the 'when/where'), (iii) the form of interaction, for example, addressing organisations in terms of credibility and comprehension of significance (the 'how'), and (iv) establishing exchange resources for the participant components of the interaction (the 'what/which'). Given the expectations for IDR in terms of producing pioneering inventions or discoveries, interaction management can be an important and far more leveraged than improving the efficiency of execution.

In the present study, instead of establishing a normative analytical framework, we applied optimised descriptive processes through surveys or face-to-face interviews. Accordingly, the present study devises two schemes. The first scheme strives to avoid a rigid top-down approach and, instead, explores the potential for improvement at research sites, as well as striving to induce spontaneous improvement by providing interactive opportunities. The other scheme involves conducting assessments while benchmarking methods from several research institutions by applying standardised investigative and evaluative criteria. Specifically, this scheme focuses on enabling improvements by comparing viewpoints from other research groups and institutions based on actual investigative cases, facilitating researchers' intellectual curiosity about the projects of other researchers, and creating motivation by generating 'awareness' of the researchers at an individual level.

These initiatives reveal that development project management methods involving technology management require the implementation of research projects that include basic research. Our experimental study was in harmony with a continuous improvement approach in later R&D stages, as well as the climate and culture of the university and researchers.

4.2. Implications to the IDR management

This section discusses the implication to the management of research institutes from the series of results, in particular, the impact on the promotion of IDR projects, and the possibility of the application thereof.

4.2.1. Managing IDR projects

The KPI-KAI framework can be primarily applied to effectively promote IDR projects. As described in the introduction section, many previous studies have been carried out to understand the significance and validation of IDR projects. On the other hand, as discussed in the section, the management at research institutes has not been sufficiently discussed in spite of its importance. Future

research in academic organisation management needs to explore the means to fill the gap between these needs and the methodology as well.

The previous case example in the U.S. presents one viewpoint [35]. In this report, each of the following factors are fundamental to promote IDR at universities and public research institutions: (i) innovative changes in organisational structures, (ii) research fund distribution that is not dependent on the conventional academic system, (iii) employment of faculty that does not depend on the conventional framework of departments or school ties, (iv) setting up employment/promotion standards of faculty members along the value standards of interdisciplinary fusion, and (v) continuous consideration of interdisciplinary fusion research implementation process. Eight obstructions and approaches to overcome them are specifically listed further.

In addition, numerous business management approaches for research and development management have been proposed in the industrial world. Managerial approaches such as Activity Based Costing (ABC), Balanced Score Card (BSC), and Business Process Management (BPM), are typical examples that are applied to the management of many corporations today. Particularly, as a modern project management system, Project Management Body of Knowledge or PMBOK proposed by the Project Management Institute [36] forms a standard in research and development management.

The time has come to develop business management approaches at universities/research institutions in the coming years to facilitate goal setting or process management in academic basic research with reference to theories by these previous studies or practices in the industrial world.

4.2.2. Managing IDR talents and human resources

One of the applications of this KPI-KAI framework is human resources management at IDR institutions. In this paper, human resources management is generally classified into performance management of researchers and personal evaluation of each individual.

KAIs are complementary management tool to KPIs. One of its advantages, as shown in this study, is that evaluation between two research institutes with different locations and objectives will be sufficiently possible through common evaluation indices and items. In other words, if individual researchers compare the activity situation of affiliated research institutes with best practice or other practices, or monitor the activity situation over time, relative confirmation as well as real-time discussion and implementation of necessary improvement plans will become possible. To introduce such performance management, organisational healthiness that will allow and recommend visualisation and sharing of investigation results, scientific analysis, and positive application, are prerequisites.

For personal evaluation, aggressive application of KAIs as process evaluation, in addition to KPI as performance evaluation, is important. In particular, it is also envisioned that researchers who have newly moved from single field research projects to IDR projects will have a longer lead time and time lag until the generation of the research outcome versus those researchers who are familiar with IDR. In such a case, the possibility of under-estimating the ability of newly participating researchers cannot be dismissed if performance evaluation was carried out only with KPIs. On the other hand, if KAIs are indexed and achievement thereof is evaluated, situations during the course of the approach can be confirmed, and evaluation, according to its progression, will become possible to some degree.

From the viewpoint of research institutions which promote IDR, it is important to establish the methodology to match the expertise of the researchers with different disciplines and to organize the IDR teams. In the case of CNBI, the management members defined three core area for the research before starting this project and assigned the project members who could share the similar goal to the three teams accordingly. After this, management highly promoted matching of expertise and collaborative research inside the team. In the case of the WPI-iCeMS, same to the manner at CNBI, the leadership defined the mission and vision of the centre based on the common mission statements set by the entire WPI Program: leading science, global perspective, fusion science, reform. Furthermore, the WPI-iCeMS intentionally formed three domains of expertise i.e. cell biology, chemistry and physics, at the beginning phase of operation and all the staffing process was undertaking in accordance with the domain criteria.

4.2.3. Managing IDR institutes

As described hitherto, reinforcement of a management system at academic research institutes is essential today. In the future, we must attempt to establish an academic research management body while striving to understand and reflect on rules or division of the labour system specific to academic organisations, but we must always be aware of being universal or systematisation as scientific/technological management research.

The evaluation approach based on KAI-KPI presented in this study, and the quantitative and qualitative analysis framework provides many suggestions for organisational policy of research institutes, in particular, the optimisation of communication opportunities such as operation of conferences or symposia, procurement of resources that are not sufficient with individual researchers or laboratories for IDR projects, and seeking intervention from the research institutes. We expect that the managerial approach extracted by the method suggested in this paper will lead to identification of the so-called PDCA (plan, do, check, and action) cycle or best practice in research and development at research institutes.

In addition, this study proposes a new practical academic system that integrates social and natural science i.e. researchers of social sciences, including businesses and applied economics, playing a central role in close collaboration with researchers of natural sciences, who may be central players in collaboration research. It is by no means impossible to form new research areas of scientific/technological management and innovation theory, and further expand this approach to research management at universities and public research institutions in general.

In order to in incentivise young researchers for IDR, both CNBI and WPI-iCeMS had several tools including a small research funding for internal researchers to start and accelerate the IDR. In the case of CNBI, even non-PI researchers could make short research presentations at the annual meetings with participation of all the members, providing them with an opportunity for the new collaboration with senior PIs with different disciplines and for their career development. The WPI-iCeMS has been taking a similar approach to that at CNBI to facilitate internal peer-to-peer interaction for mutual understanding of activities and prospective discussion for IDR by holding yearly retreat as an intensive communication opportunity.

4.2.4. Managing IDR policy programmes

Research institutes, based on competitive funds, typically demand an interim report by performing an on-site review or peer reviews during the project. In such a case, setting of the evaluation criteria is extremely important for self-evaluation by operation members of the research institutes. Moreover, determining the achievement goal of the research project demanded from the government/research aid agencies that plan/publicly offer competitive funds as well as forming an agreement related to evaluation within research institutes, will be essential in this process. In such self-evaluation, reporting by KPIs, such as the number of articles or the number of patents as well as quantitative presentation of the monitoring result of KAIs at the institution level, are thought to be effective. In doing so, qualitative comprehension of KAIs by a survey of affiliated researchers as well as broad extraction of future tasks of the operation should also be done.

For evaluation at the end of the research project or ex-post evaluation, it is desirable to report the ultimate achievement status of KAIs and KPIs that were set at the time of grant application. A certain quantitative evaluation is possible for early-stage articles, even for the number of backward citations of articles, which is a KPI that is difficult to evaluate during the research project. In addition, sufficient description is also necessary for the diverse propagation effect of the research project. Further, the change in answer results of the questionnaire at the time of the interim report due to a later managerial approach should be sufficiently applied in reporting opportunities, because they directly show the organisational management effort at the research institute.

4.3. Limitations of research and future prospects

The policy for elaboration/visualisation of the evaluation index based on more elaborate data as well as a flexible framework for the improvement trial thereof, and the policy for research activity promotion has been described above. However, the limitations of this ground-breaking research and the direction of approach towards the future must also be clarified.

This study conducts analysis and discussion that is targeted at research institutes of IDR having life sciences as the basic axis. Accordingly, whether the discussed business management approaches are applicable to other fields must be sufficiently examined. To this end, comparison with research institute programmes in other fields must be further expanded.

In addition, investigation target researchers are also limited. Only principal investigators were targeted in this study. However, many junior faculty members and research associates are enrolled, and evaluation of their contribution was not performed. Moreover, education activity which is one of the most important roles of universities was not the subject of evaluation because all of the case examples were research departments. It is essential to encompass each of the previous points to establish a more universal/comprehensive business management style.

The interdisciplinary index, which is a KPI employed in this research, was calculated based on the academic publication data. However, achievements of academic research are not necessarily limited to publications. In particular, focusing on economical values generated by the outcomes of scientific technology (for example, creation of patents, transferring/licensing of patents to private corporations, etc., and distribution of products/services by these private corporations) are essential evaluation indices in discussing innovation from universities and public research institutions.

Accordingly, a research project management style related to collaboration between industry and academia must be elaborated. Specifically, extraction of requirements demanded of universities and public research institutions that are necessary for the promotion of collaboration between industry and academia activity should be the top priority. It is necessary for these institutions and private corporations/venture corporations to perform measurement surveys for cooperation of industry and academia in a bid to attempt multi-layering of evaluation standards and adaptation to industrial/social needs.

In that sense, the quantitative survey result obtained in the demonstrative research is still at a nascent stage. Further, even as a theory of movement in actual organisations, this is implemented only by repetitively/continuously performing comparison between research institutes, job positions, fields, and research groups rather than completing such an approach in a single turn, as well as through repeated optimisation effort of KPIs and KAIs. In other words, it is vital that the research outcomes of scientific/technology management are sequentially returned to the on-site scientific/technology management or project management. The study will become action-based only when practice outcomes are applied to strategy building of academic research project through reinforcement of the PDCA cycle.

CONCLUSION

This study aims to effectively promote IDR, and attempts to develop a business management style that includes the approaches of scientometrics, organisation management, and technology management. As for the policy, KPIs and KAIs were defined, and indices were set from the three analytic observation angles of transaction partners, transaction resources, and communication opportunities for KAIs, and an interdisciplinary index based on publication information was set for KPIs. Then, an action style expressed by KAI was observed based on case studies at the two research institutes, and the

impact of KAI on KPI was analysed. As a result, common characteristics were seen for each KAI from: the preference of communication partners, the importance of communication element and organisational complementation, the importance of transaction resources, the outcome of organisational approach, the impact of communication opportunities, and the preference of management method on KPI. Further, the meaning of management of IDR projects or human resources as well as in management of research institutes or policy programmes was discussed. This series of results and discussions illustrates that organisational interdisciplinary cooperation management is effective in universities and public research institutions, and suggests that this approach should be more deeply cultivated through both theory and practice.

CONFLICT OF INTEREST

The authors have no other relevant affiliation with a financial interest in or financial conflict with the subject matter mentioned in this manuscript.

This research is part of an approach at the Funding Program for World-Leading Innovative R&D on Science and Technology by the Ministry of Education, Sports, Science and Technology of Japan (MEXT, TA), the World Premier International Research Center Initiative Program (WPI Program) by MEXT (SS) and the Center of Innovation Program from MEXT and JST (TA and SS). This research is financially supported by Grant-in-Aid for Scientific Research by the Japan Society for the Promotion of Science (grant no. 26285084, SS), the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program) initiated by the Council for Science and Technology Policy (CSTP, TA).

ACKNOWLEDGEMENTS

All individuals listed as authors contributed substantially to the design, performance, analysis, or reporting of the work. Relevant persons at C&C Innovation Research Laboratories of NEC Corporation (CCIL, Ikoma City, Nara Prefecture) substantially cooperated with this research by providing case examples. We thank Professors Cihiro Suematsu and Takanori Ida of Kyoto University for providing advices; Professors Kazuhiro Kataoka and Ung-il Chung of the University of Tokyo for their cooperation to the empirical research. Our gratitude is extended to each of the parties listed above.

REFERENCES

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

[2] Corley E, Boardman C, Bozeman B. Design and the Management of Multiinstitutional Research Collaborations: Theoretical Implications from Two Case Studies. Res Policy 2006; 33: 975-93.

[3] Nightingale P, Scott A. Peer review and the relevance gap: Ten suggestions for policy-makers. Sci Public Policy 2007; 34(8): 543–53.

[4] Gibbons M., Limoges C, Nowotny H, Schwartzman S, Scott P, Trow M. The new production of knowledge: The dynamics of science and research in contemporary societies. London: Sage; 1994.

[5] Hage JT, Hollingsworth R. A strategy for analysis of idea innovation networks and institutions. Org Studies 2000; 21: 971–1004.

[6] Stirling A. A general framework for analysing diversity in science, technology and society. J Royal Soc Interface 2007; 4: 707 –19.

[7] Rafols I, Leydesdorff M, O'Hare A, Nightingale P, Stirling A. How journal rankings can suppress interdisciplinary research: A comparison between Innovation Studies and Business & Management. Res Policy 2012; 41(7): 1262–82.

[8] Shibata N, Kajikawa Y, Takeda T, Sakata I, Matsushima K. Detecting emerging research fronts in regenerative medicine by the citation network analysis of scientific publications. Technol Forecasting Soc Change 2011; 78: 274–282.

[9] Anzai T, Kusama R, Kodama H, Sengoku S. Holistic observation and monitoring of the impact of interdisciplinary academic research projects: An empirikodamcal assessment in Japan. Technovation 2012; 32: 345–57.

[10] Kodama H., Watatani K., Sengoku S. Competency-based Assessment of Academic Interdisciplinary Research and Implication to University Management, Research Evaluation 2013; 22: 93-104.

[11] Lauto G, Sengoku S. Perceived incentives to transdisciplinarity in a Japanese university research center, Futures 2014; doi: 10.1016/j.futures.2014.10.010.

[12] Harhoff D, Narin F, Scherer F, Vopel K. Citation frequency and the value of patented inventions. Rev Econ Stat 1999; 81(3): 511–5.

[13] Lanjouw J, Schankerman M. The quality of ideas: Measuring innovation with multiple indicators. NBER Working Paper 1999; 7345.

[14] Jaffe A, Trajtenberg M, Fogarty M. The meaning of patent citations: Report on the NBER/Case-Western Reserve Survey of Patentees. NBER Working Paper 2000; 7631.

[15] Oppenheim C. The correlation between citation counts and the 1992 research assessment exercise ratings for British library and information science university departments. J Documentation 1995; 51(1): 18–27.

[16] Oppenheim C. The correlation between citation counts and the 1992 research assessment exercise ratings for british research in genetics, anatomy and archaeology. J Documentation 1997; 53(5): 477–487.

[17] Rinia E, van Leeuwen Th, van Vuren H, van Raan A. Comparative analysis of a set of bibliometric indicators and central peer review criteria evaluation of condensed matter physics in the Netherlands. Res Policy 1998; 27(1): 95–110.

[18] Katila R, Ahuja G. Something Old, Something New: A Longitudinal Study of Search Behavior and New Product Introduction Acad Mgt J 2002; 45(6): 1183-94.

[19] Hayashi T. Is bibliometrics useful to support peer review? A case study of NIAD's research evaluation in science. Res Univ Evaluation 2003; 3: 169–87.

[20] Gibbons M, Georghiou L. Evaluation of research: A selection of current practices. Paris: Organisation for Economic Co-operation and Development (OECD) 1987; Chapter III.

[21] Porter A, Cohen A, Roessner D, Perreault M. Measuring researcher interdisciplinarity. Scientometrics 2007; 72(1): 117–47.

[22] Rafols I, Meyer M. Diversity and network coherence as indicators of inter-disciplinarity: Case studies in bio-nanoscience. Scientometrics 2010; 82(2): 263–87.

[23] Leydesdorff L, Rafols I. Indicators of the interdisciplinarity of journals: Diversity, centrality, and citations. J Informetics 2011; 5: 87–100.

[24] Wagner CS, Roessner JD, Bobb K, *et al.* Approaches to understanding and measuring interdisciplinary scientific research (IDR): A review of the literature. J Informetrics 2011; 165, 14–26.

[25] Suematsu C, Makabenta-Ikeda M. Interface from transaction cost approach. Kyoto Economic Review 2006; 84.

[26] Hamada S, Shibata A, Urushihara H, Sengoku S, Suematsu C, Kawakami K. Transaction Cost Analysis of the New Drug Application Process: A Case Study of a Multinational Pharmaceutical Company in Japan. Therapeutic Innovation Regulatory Sci 2014; 48(3): 371-7.

[27] Klein JT, Porter AL. Preconditions for interdisciplinary research. In: Birnbaum-More PH, Rossini FA, Baldwin DR. International Research Management. Oxford: Oxford University Press 1990; pp. 11-9.

[28] Hage JT. Organizational innovation and organizational change, Annual Rev Sociol 1999; 25: 597-622.

[29] Heinze T, Shapira P, Rogers JD, Senker JM. Organizational and institutional influences on creativity in scientific research. Res Policy 2009; 38: 610-23.

[30] Jordan GB. actors Influencing Advances in Basic and Applied Research: Variation Due to Diversity in Research Profiles. In: Hage J, Meeus M, Innovation, Science, and Institutional Change: A Handbook of Research. Oxford: Oxford University Press 2006; pp. 173-95.

[31] Shenhar AJ. One Size Does Not Fit All Projects: Exploring Classical Contingency Domains. Mgt Sci 2001; 47(3): 394-414.

[32] Boardman C, Corley, E. University research centers and the composition of research collaborations. Res Policy 2008; 37: 900-13.

[33] Haythornthwaite C. Learning and knowledge networks in interdisciplinary collaborations. J Am Soc Info Sci Tech 2006; 57(8), 1079–92.

[34] Hall B, Jaffe A, Trajtenberg M. The NBER patent citations data file: Lessons, Insights and methodological tools. CEPR Discussion Paper 2001; 3094.

[35] Committee on Facilitating Interdisciplinary Research. Facilitating Interdisciplinary Research. 2004. Available from: http://www.nap.edu/catalog.php?record_id=11153 [cited: 30th Sep 2015].

[36] Project Management Institute. A guide to the project management body of knowledge, 3rd ed. Newtown Square: Project Management Institute 2004.

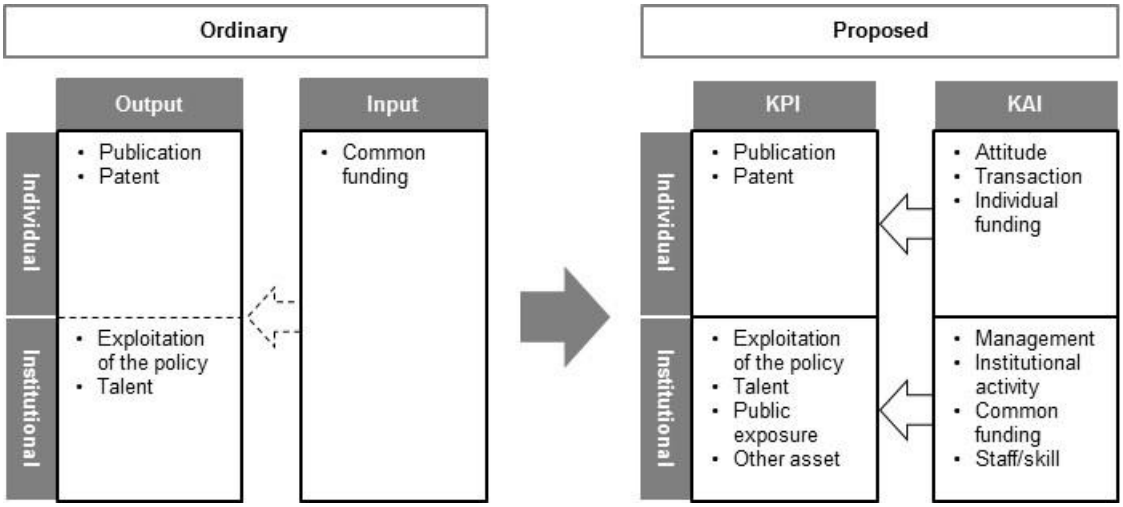

Fig. (1). The KPI-KAI Framework. This figure schematically describes the concept of an ordinary managerial framework and the proposed framework in this study. The ordinary model has three issues: (i) elements of the input side were not fully identified, (ii) the relationship between input and output has not been addressed, and (iii) institutional outputs have not been well defined, and thus have not been evaluated. To overcome these problems, the proposed framework defined key performance indicators (KPIs) and also key activity indicators (KAIs) at both individual and institutional levels. Furthermore, the contribution of these KPIs to the KAIs was statistically examined through regression analyses.

Table 1. Items for investigation and analysis.

Classification	**Initialising**	**Planning**	**Executing/controlling**
Reflection to the management of interdisciplinary research	Searching collaborators	Negotiating the collaboration	Sourcing
	Proposal for a collaborative research project	Agreement on the collaboration	Promoting the project
			Generating interim and the final results
Survey items	Preference on communication partners	Preference on communication partners	Preference on communication partners
	Preference on opportunities for communication	Importance of communication elements and organisational complementation	Preference on management methods for communication
			Importance of resource items and organisational complementation

Table **2**. The overview of two research institution examples.

Description	**Center for NanoBio Integration (CNBI)**	**The Institute for Integrated Cell-Material Sciences (iCeMS)**
Organisation	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 FY2010
Annual Average	JPY 0.51 billion	JPY 1.35 billion in FY2010
Number of Researchers (PIs)	114 (33) as of the end of FY2010	174 (18) as of the end of FY2010
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

Table **3**. Primary preferences of communication partners in each phase of the IDR projects with researchers in different fields.

Questionnaire	**Initialising**			**Planning**			**Executing/ controlling**		
	CNBI	**iCeMS**		**CNBI**	**iCeMS**		**CNBI**	**iCeMS**	
(1) The PI or equivalent of your affiliated research group (laboratory)	4.31	4.92		4.40	4.75		4.25	4.42	
(2) Researchers other than (1) in your affiliated research group	4.05	4.00		4.17	4.15		4.28	4.11	
(3) Researchers other than (1) and (2) in your affiliated department	3.47	3.23		3.33	2.93		3.55	3.07	
(4) The representative of the research group of the different field	4.53	4.67		4.47	4.74		4.52	4.61	
(5) Researchers other than (4) in the research group of the different field	4.42	4.15		4.44	4.26		4.56	4.25	
(6) Researchers other than (4) and (5) in the department	3.53	2.89	**	3.39	2.59	***	3.58	2.64	***
(7) Researchers other than the above that belong to the academic society of your research field	3.06	2.78		2.67	2.30		2.66	2.25	
(8) Researchers other than the above that belong to the academic society of the different field	2.88	2.85		2.61	2.26		2.47	2.18	
(9) Administrative department of your affiliated research department				2.77	2.78		2.72	2.82	
(10) Administrative department of the department the collaborative research partner belongs to				2.63	2.70		2.63	2.50	
(11) Academic media such as articles database and journals	3.56	3.89							
(12) Other medias such as newspapers and television	2.73	2.56							
Mean of the items above	3.65	3.59		3.49	3.35		3.52	3.28	

*** p<0.01, ** p<0.05, * p<0.1.

Table **4**. The importance of various elements for communication and the degree of complementation by each project in the planning phase of IDR projects.

Questionnaire	**Importance**			**Organisational complementation**		
	CNBI	**iCeMS**		**CNBI**	**iCeMS**	
1) Language skills	3.20	3.71	*	3.27	3.75	*
2) Physical distance	3.69	2.89	***	3.95	3.96	
3) Sense of values	4.44	4.21		3.61	3.25	
4) Credibility	4.73	4.79		4.06	3.96	
5) Comprehension of significance	4.56	4.54		3.91	3.75	
6) Logicality	4.17	4.21		3.52	3.36	
7) Research approach	4.25	4.18		3.86	3.54	
8) Specialised knowledge	4.00	4.21		3.94	3.57	

*** p<0.01, ** p<0.05, * p<0.1.

Table **5**. The importance of resources and the degree of organisational complementation thereof in the implementation phase of IDR projects with researchers of different fields.

Questionnaire	**Importance**			**Organisational complementation**	
	CNBI	**iCeMS**		**CNBI**	**iCeMS**
1) HR (project leaders)		4.92	*		3.92
2) HR (other researchers)	4.69	4.93		3.79	3.84
3) HR (technicians/assistants)	4.05	4.14		3.49	3.76
4) Physical assets	4.38	4.43		4.06	3.84
5) Intangible assets	4.30	4.21		3.55	3.76
6) Info. exchange opportunities	4.23	4.21		4.23	3.96
7) Funds (direct expenses)	4.53	4.54		3.83	3.72
8) Funds (indirect expenses)	4.39	4.57		3.26	3.68
9) Authority	4.20	4.25		3.53	3.52
10) Administrative tasks	3.53	3.56		3.09	3.28
11) Operation know-how	3.67	3.36		3.32	3.16
12) Brand	3.53	3.54		3.64	3.60
13) Platform	3.89	3.64		3.72	3.56

*** p<0.01, ** p<0.05, * p<0.1.

Table **6**. Multiple regression models with interdisciplinarity and survey results related to the usefulness and participation frequency of communication opportunities.

Variable	**Usefulness**			**Frequency**		
	β		**SE**	**β**		**SE**
1) Hosted international symposia				0.88	**	0.04
2) Faculty meetings				-0.20		0.03
3) Other meetings or gatherings within the institute	0.52	**	0.02	-0.77	**	0.05
4) Other meetings or gatherings within other departments	0.55	*	0.03			
5) Academic conferences and symposiums				-1.61	***	0.05
6) External committee activities	-0.20		0.02	2.05	***	0.04
Constant		***	0.11		***	0.12
N	28			28		
R^2 adjusted for the degrees of freedom	0.43			0.58		

*** p<0.01, ** p<0.05, * p<0.1.

Table **7**. A multiple regression model with and survey results related to communication management method.

Variable	**β**		**SE**
1) The conference/meeting is scheduled with sufficient leeway in time	-0.16		0.03
2) The agenda is specifically set and shared	0.44	**	0.02
3) Discussion materials are prepared beforehand and shared 4) Materials of other presenter are distributed at the meeting 5) PI or representative is attending 6) Time and number of topics are appropriate	0.58	**	0.03
7) The participants are earnest	-0.25		0.03
8) The participants are actively speaking out 9) There are few conflicts in opinions	0.19		0.02
10) The meetings are operated smoothly 11) Late arrival and early dismissal are allowed	-0.37	*	0.02
12) Action items and future plans are clear after meetings	-0.41	*	0.02
13) The meeting minutes are created and circulated after the meeting	0.33	*	0.02
Constant		***	0.14
N	28		
R^2 adjusted for the degrees of freedom	0.33		

*** p<0.01, ** p<0.05, * p<0.1.