Factors that Impact Interdisciplinary Natural Science Research Collaboration in Academia[1]

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Abstract
Interdisciplinary collaboration occurs when people with different educational and research backgrounds bring complementary skills to bear on a problem or task. The strength of interdisciplinary scientific research collaboration is its capacity to bring together diverse scientific knowledge to address complex problems and questions. However, interdisciplinary scientific research can be difficult to initiate and sustain. We do not yet fully understand factors that impact interdisciplinary scientific research collaboration. This study synthesizes empirical data from two empirical studies to provide a more comprehensive understanding of interdisciplinary scientific research collaboration within the natural sciences in academia. Data analysis confirmed factors previously identified in various literatures and yielded new factors. A total of twenty factors were identified, and classified into four categories: personal, resources, motivation and common ground. These categories and their factors are described, and implications for academic policies and practices to facilitate and sustain interdisciplinary collaboration are discussed.

Introduction

Collaboration is human behavior that facilitates the sharing of meaning and completion of tasks with respect to a mutually shared superordinate goal, and which takes place in a particular social or work setting (Sonnenwald & Pierce, 2000). Interdisciplinary collaboration occurs when people with different educational and research backgrounds bring complementary skills to bear on a problem or task. Interdisciplinary collaboration is often needed to address complex problems, the solutions to which require knowledge and resources from more than one discipline. Clark (1995) identified over 8530 disciplines and fields of knowledge. During interdisciplinary scientific collaboration, scientists exchange tools and methods, utilize diverse paradigms and cross-fertilize disciplinary concepts (Klein, 1994). Differences in tools, methods, paradigms and concepts may increase the likelihood of contested collaboration (Sonnenwald & Pierce, 2000), where collaborators challenge each other's contributions. This may strengthen a collaboration, however, when challenges are managed in an unproductive manner, it negatively impacts work. We do not yet fully understand all of the factors that facilitate and/or are barriers to interdisciplinary scientific research collaboration and the role of such factors in the scientific process.

Therefore, the goal of this paper is to explore factors involved in interdisciplinary scientific research collaboration. Our focus is on natural science research in academia. To address these issues, we conducted two empirical studies; an interview study and longitudinal field study. In the interview study, 22 scientists from academic research institutions who had participated in both inter- and intra-disciplinary research collaborations were interviewed. The interviews consisted of a semi-structured interview protocol that was based on the factors suggested in various research literatures. The setting for the longitudinal study was an interdisciplinary research center that included approximately 35 faculty and 70 students distributed across five universities. Center meetings were observed and interviews were periodically conducted over five years. All data were analyzed using a grounded theory approach (Glazer, 1998) to help illuminate factors that appear to be facilitators and/or barriers in interdisciplinary scientific research collaboration.

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The analysis identified twenty factors which were classified into four categories: personal, resources, motivation, and common ground. Many of the factors were previously identified in research literature on small groups, business, psychology, information science, education, social studies of science and science policy, but they were not necessarily associated with interdisciplinary scientific research collaboration. Several new factors also emerged from the data analysis. These new factors include: common professional traits, students, and literature that helps scientists learn about new fields. These results suggest various innovations in academic policies and practices are needed to facilitate and sustain interdisciplinary scientific research collaboration.

Research Methods

Interview Study Data Collection
To investigate the factors that impact interdisciplinary scientific collaboration, interviews were conducted with 22 scientists and engineers who had participated in both inter- and intra-disciplinary collaborations. The participants were identified through web pages, mutual contacts and recommendations from other scientists using a snowball sampling approach. They were natural scientists (astronomy-2, biology-5, chemistry-4 and physics-6) and engineers (chemical engineering-3 and computer science-2) from 16 research I universities and 6 research centers/labs in the southeast USA. The average time each had spent collaborating was 11 years with a range of 2-30 years, and the average percentage of time spent in inter- vs. intra-disciplinary collaborations was 65 vs. 35%.

A semi-structured interview protocol was developed based on the research in various disciplines discussing collaboration. Questions focused on specific factors that have been shown in the literature to effect collaboration. Participants were asked whether these factors have affected, positively and negatively, both their inter- and intra-disciplinary collaborations, and if so, how. General questions about the collaboration process were also asked to allow the participants to suggest factors that might not have been identified in other studies. Examples of questions include: "How did you come to be involved in interdisciplinary collaboration? Why did you decide to be involved in this collaboration? How does this collaboration fit with the rest of your priorities? Does the department that you work in support the collaboration? What are the roles of people collaborating on this project?" The objective was to elicit data not only about what factors affected the participant's collaborative research experiences but also why those factors affected the collaboration process. Each interview lasted 57 to 95 minutes, with an average length of 83 minutes. The interviews were captured on audiotape and later transcribed.

Longitudinal Field Study Data Collection
The setting for the longitudinal field study was an interdisciplinary research center in the USA. Initially, the Center had approximately 30 faculty scientists and 82 students and postdoctoral fellows, and three full-time staff members physically located at four different universities in the USA. Membership changed over the years, and after three years there were approximately 45 faculty scientists, 70 students and postdoctoral fellows and three full-time staff members located at five U.S. universities. The Center was first funded late 1999, with a five-year $15 million dollar commitment from a national funding agency with matching support from several participating universities, corporations and a non-profit foundation.

The field study began during the beginning stages of the center and continued for three years. While conducting the field study, the second author was a participant observer, having both complete and peripheral membership roles. As a complete member, she served as the Center Coordinator of Social Science Research Efforts and a member of the Center management team. She actively participated in the management meetings, contributing to discussions and participating in decision-making. However, when the meetings and decision-making focused on research in natural science and engineering, she assumed the role of a peripheral member. She observed the activity, taking notes and audio-recordings, and discussed events and outcomes with meeting participants. The second author was also a peripheral member participant in center-wide weekly research meetings, generally observing discussions. Observation data included transcribed audio-recordings of meetings, video-recordings of videoconferences, meeting and centre documentation and researcher notes.

Data Analysis

The interview and observation data were first analyzed separately, and then synthesized. Interviews were analyzed using an iterative coding process. The first step was open coding to identify factors; the second step was axial coding to verify factors and identify relationships among them. Grounded theory (Glaser, 1998) was used throughout coding of the interview data in order to note any factors or themes that had not previously been addressed in the literature. The coding sought to illuminate themes and trends across the interviews, both within and between subjects, so that a greater understanding of factors that are facilitators and/or barriers in interdisciplinary academic scientific collaboration would emerge.

Observation data were similarly analyzed in the grounded theory tradition (Glaser, 1998.) The data were thoroughly analyzed for patterns within the data and the meaning of those patterns. These results were synthesized with the results of the interview data analysis to suggest a more comprehensive understanding of factors that appear to impact interdisciplinary scientific collaboration.

Results

Four categories of factors emerged from the data analysis. These are: personal, resources, motivation, and common ground. Each category is described below.

Personal Factors

Factors in the personal category characterize collaborators' preferences, abilities, feelings and perceptions. The factors related to personality that emerged from the data analysis include: expertise, social networks, trust, personal compatibility, and common professional traits. Expertise is the knowledge and skill, such as knowledge of previous research, techniques and methods, that a person brings to a collaboration. Access to and the combining of a variety of expertise often promotes collaboration (Thorsteinsdottir, 2000). As one study participant commented:

> *So usually there are these projects that really do require very different skills to come to an end goal.*

A scientist's social network, or collection of collegial relationships, may influence collaboration by providing access to resources (including other scientists) and expectations regarding behavior (Traore & Landry, 1997). In most cases this factor was referenced in conjunction with personal contacts and introductions to possible collaborators:

> *[Our collaborators] will be our personal contacts, networking and finding who is interested or who could benefit from what we are developing.*

Trust or faith in another person's scientific skills, ethics or ability to collaborate also appears to be a factor in interdisciplinary science. One scientist commented:

> *You try to trust people.*

A judgment that another person would be enjoyable to work with, personally compatible, or not, is also an important factor in collaboration. As one scientist explained:

> *It's… like dating. I think the important thing is that you get along. You know, you are able to have a dialogue with the people you're working with.*

Common professional traits are personality characteristics that would lead a scientist towards interdisciplinary research. That is, study participants referred to common traits, or general characteristics, of scientists to explain why interdisciplinary collaboration might occur. This factor has not been reported previously in the literature. Examples of common traits mentioned are:

> *I think scientists are just by nature curious. They like to learn new things, and by learning the important things about the other discipline, I think it enhances their ability to be innovative in [their] approach [to research].*

> *[Interdisciplinary collaboration is] different, it requires a little more adventuresome spirit.*

I think, by nature when you get into science, you like to learn, and you like problem solving… I think it's in scientists' personality in general to just like to learn new things all the time.

Overall, the factors in the personal category were discussed most often in conjunction with the initiation process of the collaboration. This is not surprising given that collaborations frequently occurred between people who had not known each other well prior to the collaboration and the foundations for their interpersonal exchanges and negotiations occurred during this phase of the collaboration process.

Resource Factors

This category highlights resources needed by scientists to support interdisciplinary science. Specific resource factors that emerged from the data analysis are: support from funding agencies, support from scientists' institutions, literature, scientific publishing, students, and time.

Support from funding agencies typically includes funds and resources necessary to pursue the collaborative research. Knowledge that funding agencies may favor interdisciplinary research appears to encourage interdisciplinary collaboration (e.g., Beaver, 2001). One scientist commented:

> *I just came from a workshop…on the challenges for the twenty-first century in chemistry. And obviously what came up [was] whether they should give more funding to single investigators…because they're not solving the tough problems.*

Study participants also reported that support from a scientist's institution was important. Institutional support may include resources and encouragement to pursue the research, as also mentioned by Slater & Hearn (1996). But institutional support may be limited or lacking. Participants reported:

> *The departments are in a tugging war for the indirect costs that come with a grant. And so, whichever department gets to be the manager of the grant, wants to keep all the money and then just dish it out to the other departments because they get to keep a fraction of the indirect costs.*

> *So there's kind of... territorialism that…has worked its way into everything, and so you kind of have to un-work it out of everything that you want to do… and there are some people…that thought of [our] project as "oh, that's computer science taking some of physics' space."*

The factor, literature or publications, refers to literature scientists use to learn about new fields and opportunities for collaboration. Publications can help bring potential collaborators together as well as help inform scientists about their collaborators' research area. Scientists commented:

> *[Our research] was always in the news… and people wanted to participate.*

> *I'd go look at what the papers they'd written…we had this conversation that lasted for forty-five minutes or something, and I can't know everything about what that person's work is like…So I... look up the papers that they've written and see, yeah, that is an interesting topic…[or] this sounds really bogus.*

> *He would recommend chapters to read in sort of introductory computer science texts…and so that would help me get up to speed. And I would recommend to him genetics texts, genetics books and things.*

Another factor, scientific publishing, refers to papers and publications that the scientists plan to write, or have written, in collaboration with others. This was seen as both a facilitator and a barrier primarily during the final stages of the collaboration when the scientists are writing the papers, determining content and deciding where publications should be submitted. There are multiple issues surrounding the writing of papers, including the decisions on where to publish the article and authorship. These decisions may positively or negatively impact a scientist's career. Participants in other studies have also noted that author order can vary from discipline to discipline (e.g., Katz & Martin, 1997). Scientists we interviewed reported:

> *In biochemistry and chemistry, the last author is always the corresponding author. That's the person who paid for the work, and the first author is the one who did the work… [but] that's different in different fields.*

> *Well, [determining publication credit is] always a problem…The bean counters are the people who are going to evaluate these and, for example, if you're in a medical department and you get a publication in a scientific journal where you're the fourth author, is your chairperson going to give you credit?*

Students, a human resource, emerged as another factor in the collaboration process in this and other studies (e.g., Beaver, 2001). Students facilitate collaboration by conducting background research, running experiments and acting as communication bridges between collaborators. Students were viewed as facilitators in every stage of the collaboration process, although they were never discussed in conjunction with intradisciplinary research. Furthermore, interdisciplinary experience was viewed as a beneficial for students. Scientists explained:

> *So we had an undergraduate [computer science] student who… saw this physics professor over in physics…and told him about [our] project… [The professor said:] "We've heard all this hype… [And] we don't need [their research tools]"… [But] after about six months or so he came over and tried it out and…now he's like "Whoa."*

> *[We had a student who was] a mathematical biology student...and so I was able to talk to him very easily. He was [also] able to talk to [the computer scientists]… I never would have been able to talk to the computer scientists directly.*

> *And I think [interdisciplinary collaboration] is… a better training for the students because they're learning two different things at the same time… It's a project that the students learn more from because they're working together with people from different disciplines which is the way life works.*

Participants, in this and other research (e.g., Finholt, Sproull & Kiesler, 2002), made frequent references to time as a limited quantity resource. Scientists reported that, when compared to intradisciplinary collaboration, more time was required to start new interdisciplinary collaborations. The advantage, however was that by combining resources during a collaboration, they could reduce the amount of time needed to perform some experiments.

> *[Interdisciplinary collaboration] is incredibly time-consuming… one needs to be prepared to put a lot of time and effort into that.*

> *The disadvantage is that it's much harder to organize.*

> *We had all the expertise with the [specialized scientific instrument]. We know how to make it dance. He knows how to make his biochemical system dance. Right? And so, then they dance together…whereas if he were somewhere trying to do this by himself, it would be much harder. It would have taken him months.*

Motivation Factors

Factors that appear to motivate interdisciplinary collaboration are: learning and teaching, new discoveries, fun, and external rewards.

The process of learning and teaching has been identified as a factor in collaboration in other research (e.g., Klein, 1994) and was frequently referred to as integral to the interdisciplinary collaboration process in our studies. The very nature of interdisciplinary collaboration requires that participants teach and learn from each other so that they have a common ground from which to work. This exchange of diverse knowledge can facilitate the progression of scientific knowledge but, given the time and effort often required, this exchange is also viewed as a barrier to collaboration. Participants explained:

> *[Interdisciplinary collaboration is] more stimulating intellectually because you're not doing the same thing the same way all the time, you are learning new things outside of your area. And you're teaching outside your area, as well.*

> *I think [interdisciplinary collaboration] probably is more challenging a priori because, like I said, there's these lack of overlaps in core intellectual content. So you're having to learn a lot of things before you can really do an experiment sensibly.*

Discovering new knowledge has long been a motivation for scientific research in general (Salter & Hearn, 1996; Thorsteindottir, 2000). However, interdisciplinary collaboration often involves resolving problems in new areas which may be especially exciting and stimulating, leading to discoveries and the questioning of previous assumptions during the experimentation process. Scientists explained:

> *Well, in the modern world, progress is made in the interfaces between disciplines. I mean, that's where discoveries are being made.*

> *That's the real power [of interdisciplinary collaboration]. It's that "Oh, god I didn't even realize that I could possibly get this information"... I think that happens a lot when people start collaborating with people that are outside of their expertise.*

Scientists will also expend energy on research that they think will be fun interesting, important and/or worthwhile. One scientist expressed this as follows:

> *The people who are coming from a different disciplinary direction might have some real interesting questions that are fun to think about.*

Another motivating factor is the anticipation of receiving, or not receiving, academic or other forms of credit (Beaver, 2001; Katz & Martin, 1997). Collaborations that involve university professors often appear to be affected by the professors' academic rank and the freedom, or lack of freedom, that professors feel their rank affords. Determining who gets credit for what work and thinking about how others will view the work, can both facilitate and impede interdisciplinary collaborations. For example, participants reported:

> *A large fraction of the time, you will not get full credit before tenure for collaborations…you may learn from it, but it's not going to advance your own cause…That's paramount.*

> *I think [credit has] gotten much better for interdisciplinary science…I think because it has become an absolute necessity because of the extent of information we have in biology and physics now…so the kinds of questions we can ask, you can't do them by yourself. It's just not possible… I think twenty years ago it would be hard to get tenure with a lot of collaboration. Now, in some places, it probably still is.*

> *Tenure really does protect you from those kinds of concerns [about who to collaborate with] in a lot of ways.*

Common Ground Factors

Common ground factors encompass cognitive, physical and political common ground. All three play a role in scientific collaboration. Common ground factors identified in this research are: physical proximity, research organizations, disciplinary biases, discipline-specific language, and bridges.

References to physical proximity, including working in the same or different labs and buildings, emerged in the data analysis. Proximity can ease the collaboration process (Kraut, Egido & Galegher, 1988). Study participants reported that close proximity was particularly beneficial to the identification of potential collaborators, and monitoring the collaboration. However, distance could also help define task responsibilities among collaborators. Participants reported:

> *There's another good joke about [proximity]. It's that you should only have one bathroom in a university. Right? So everybody goes to that place once or twice a day. Or…that there should be only one place in*

the whole university that sells food. So everybody goes to that place and so we bump into each other. "Excuse me, what book is that, why are you reading it" and so on.

So when we look for a collaborator, the best thing for us is to have somebody here at [our university]…Because I can go talk to them, I can say, "What's happening with the project today"…without pestering them, running into them in the hall. And I think it makes sort of a closer relationship and everybody's more invested in it and the project goes faster.

Research organizations, such as centers, often attempt to bring together scientists who have similar research interests but different backgrounds. Research centers that foster collaboration can have a variety of forms, and can go a long way to promote the collaborative process (Klein, 1994; Kahn & Prager, 1994). Some have a physical location, others are entirely virtual, and still others are a combination of the two. Participants indicated that these centers often aid in the facilitation of interdisciplinary collaboration by providing an infrastructure on which to build and initiate collaborative research. For example:

The…Center has a plant molecular biology group, and once a month…they bring a pretty high level person. They pay for the whole thing…And then you go there on a Monday night and listen to a seminar and eat pizza. And it brings people from the three universities or more [and] the companies together.

And I learned a lot from [the center]. And it makes the projects, I think, better for the student too… [It's] there to promote [collaboration] and to help it.

Disciplines have unique characteristics. Common histories and research methods can create cohesiveness within a discipline but may also serve as a barrier to working with people in another discipline (Becher, 1989; Traore & Landry, 1997). Generalizations and biases about a discipline may prohibit individuals from even considering interdisciplinary collaboration. Scientists reported:

Physicists are kind of peculiar. They are like the snottiest possible people because they think only physics is what's worth doing and nobody who doesn't do physics isn't considered among the intellectual elite. And if I [as a physicist] stoop to working with biologists and other scientists then somehow I'm corrupting their environment.

A computer scientist wouldn't recognize [bio-informatics] as computer science, but a biologist wouldn't recognize it as biology… [It] falls into this funny area that some people aren't entirely comfortable with.

Despite disciplinary barriers, some scientists reported that interdisciplinary collaboration is becoming more widely accepted and that the scientific community is changing the way it approaches research:

Disciplines change… new disciplines are coming on and you realize how they interact, interrelate with the old ones…you can start to blend these things together…it's realizing we got to open our eyes and see what other people are doing. We'll learn some stuff, and take our own fields…a lot further by working together.

[Interdisciplinary] collaboration is a more natural thing than was the case thirty years ago… it's just the natural direction that the science is going.

Disciplines also have their own language and terminology which can be a barrier to communication when collaborating across disciplines (Kahn & Prager, 1994). It often takes time, effort and self-confidence to establish effective communication across disciplines. Study participants explained:

They [scientists from other disciplines] say things and you think you understand them but then you really don't because words have different meanings... You have to be tolerant of each other in the beginning. It's a little bit hard sometimes.

> *Being able to communicate, being able to hold on to dialogues and not being scared to ask the quote-unquote dumb questions of colleagues or collaborators…But also, conversely, to be able to explain yourself and communicate your thoughts and justify the*
> *m not in a defensive way but [in] an educated way...I think that's really important in collaboration.*
> *If you don't understand what your collaborators are talking about, they're going to not want to waste their time teaching you if you can't pick it up… they're not going to include you in the decision making process.*
>
> *Working to overcome language differences can also facilitate learning:*

Often during a collaboration, one person may help collaborators better understand one another and work together more effectively. We refer to this phenomenon as “bridging.” Previous organizational research has discussed the role of boundary spanners; individuals who span boundaries by passing on relevant information (e.g., Tushman, 1977) and the role of agents who facilitates interaction and arbitrates conflict among team members (Sonnenwald, 1996). These concepts are similar to the role of a bridge but people who act as bridges during the collaboration process may also bring potential collaborators together, understands scientific principles and practices found in the relevant disciplines, and helps resolve disciplinary differences and language barriers among collaborators.

> *You know, in some ways it sounds like you have a negotiator or something, or an interpreter, but it's not really that. It's somebody who can actually understand both aspects of it…so, this person over here and this person over there might have a lot of trouble communicating with each other, but there's this continuum between…And so there's a way to pass the information from one field to the next.*
>
> *We said we need to develop a person…another scientist…who kind of understands already this engineer and can talk to him, and also understands the scientist, so like a translator almost.*

Potential Implications

This research synthesizes diverse empirical data to propose a more comprehensive understanding of interdisciplinary scientific research collaboration in the natural sciences. A clear understanding of the factors that facilitate and/or impede the interdisciplinary collaboration process may increase the success rate of collaborative research. By anticipating barriers and capitalizing on facilitating factors, researchers, project leaders and administrators can implement policies and practices to facilitate interdisciplinary collaborations.

Our research suggests that universities and institutions that wish to cultivate rich and diverse collaborations should consider removing administrative barriers to interdisciplinary collaboration, take steps to reduce risks associated with it, and foster an environment that encourages its researchers to collaborate across disciplines. This would include policies that reduce or eliminate additional, or all, overhead costs for subcontracted grant monies when more than one department and/or institution is included on a grant. All departments who have faculty participating in a funded research project should be credited for that funding by central administration as well as in press releases, web pages, and other public relations forums. Department, or university, administration should provide the same support in terms of matching funding and resources for interdisciplinary grant proposals as they do for intradisciplinary grants. Requiring researchers who are proposing an interdisciplinary project to solicit support from each relevant department chairs greatly increases the researchers' workload and deceases their chances of success. Each department chair will typically have different priorities and allegiances, and may view the request as "giving away" resources to other departments.

When decisions with respect to tenure, promotion and salary are made, research papers published in interdisciplinary journals and conferences or in another discipline’s journal or conference could be weighted the same as, or higher than, those in traditional forums for the faculty member’s field. Universities and department should consider sponsoring activities to bring faculty from different departments together to discuss research interests as well as problems and challenges that would benefit from interdisciplinary approaches.

Changing policies and providing resources to support co-supervision of master's papers and doctoral students from different departments could also help promote interdisciplinary collaboration in the near- and long-term. Students tend to be open to learning new fields and techniques, unhampered by the constraints that faculty may feel. Students bridge disciplines, act as translators, perform experiments and synthesize ideas. Exposure to a variety of disciplines can provide students with unique skill sets and open up future research and employment opportunities they might not have had with a traditional, intradisciplinary education. Furthermore, today's students will become tomorrow's researchers. The more exposure and value they receive through interdisciplinary science, the more likely they are to continue interdisciplinary research once they finish their formal education.

Limitations

This study has several limitations. The interview protocol was semi-structured and designed to evoke the collaboration factors that the participants had experienced. Each interview was different, limiting direct comparisons among them. The participants' receptiveness to, and extensive experiences in, interdisciplinary collaboration may also bias and limit the generalizability of the results of this research.

The sample chosen may also be limiting. The scientists were from similar types of research universities in the same geographic area, rather than from many geographic areas of the USA or the world or a more diverse variety of research environments. Researchers from other locales and other research environments may have reported different factors or similar factors but with more or less frequency. Furthermore, although the choice of disciplines was broad, not all disciplines and subdisciplinary areas were included. This too may reduce the generalizability of the findings.

Conclusions

Table 1. Factors found to impact interdisciplinary scientific research

Personal	**Resource**	**Motivation**	**Common Ground**
Expertise	Support from funding agencies	Learning & teaching	Physical proximity
Social networks	Support from scientists' institutions	New discoveries	Research organizations
Trust	Literature	Fun	Disciplinary bias
Personal compatibility	Scientific publishing	External rewards	Discipline-specific languages
Common professional traits	Students		Bridges
	Time		

In summary, our analysis identified twenty factors that impact interdisciplinary scientific collaboration in the natural sciences. The factors can be classified into four categories: personal, resources, motivation, and common ground (Table 1). Many factors were previously identified in research literature on small groups, business, psychology, information science, education, social studies of science and science policy, but the factors were not necessarily associated with interdisciplinary scientific research collaboration. Several new factors also emerged from our analysis. These new factors include: common professional traits, students, and literature that helps scientists learn about new fields. Typically university and department policies and practices were created for, or oriented towards, initiating and sustaining intradisciplinary research. When a university or institution wishes to encourage interdisciplinary research, they should critically re-examine their systemic policies and practices to better understand their impact on interdisciplinary collaboration. Our results suggest various innovations in academic policies and practices, such as supporting co-supervision of master's and Ph.D. theses by faculty in different disciplines and eliminating duplicate overhead charges among departments and institutions, could facilitate interdisciplinary scientific research collaboration.

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