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Interdisciplinary research: motivations and challenges for researcher careers

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Abstract

Interdisciplinarity is a fundamental asset in today's research landscape, but its rules and habits vary from those of disciplinary approaches. This article aims to evaluate the impact of researchers' participation in interdisciplinary projects on their scientific careers. To do so, we conducted a survey of researchers working at the Centre National de la Recherche Scientifique (CNRS), the largest public, multi-disciplinary research institution in France. The survey is based on a sample of 970 respondents representative of scientists from all disciplines and involved to varying degrees in interdisciplinarity. The main results indicate that involvement in interdisciplinary projects often starts very early (PhD, post-doc), and that interdisciplinarity is not slowing down career development. Interdisciplinarity has however certain specificities like the longer duration of projects, or the absence of adequate scientific journals. In terms of valorization of scientific results, differences to disciplinary uses are found. Assessment criteria for interdisciplinary projects or careers do not take sufficient account of these specificities; they are considered inadequate to the challenges of interaction between disciplines and should be rethought. We make four proposals, which we believe essential to better recognize interdisciplinary scientific engagement.

1. Introduction

Interdisciplinary research has found a place of choice in current research, as it appears to be a necessity to address complex issues or societal challenges. Interdisciplinarity is indeed considered as a key element for the development of projects at the interface of disciplinary issues allowing the implementation of multi-scale methods and the deployment of holistic approaches to answer many of today's open scientific questions. It has thus become an important concern for many scientists and academic institutions as well as for the socioeconomic world, which has led to a growing number of interdisciplinary research programs and centers in complement to disciplinary research (Carayol et al., 2004; Porter & Rafols, 2009; Bridle et al., 2013; Van Noorden et al., 2015; LERU, 2016).

Fostering interdisciplinary research by creating a fertile research ecosystem implies to take into account the individual research context for concerned scientists. In particular career development is often questioned due to the widely admitted issue that interdisciplinary research takes more time to be implemented (Darbellay et al., 2016; LERU, 2016).

In this context, this article discusses the impact on research careers of the engagement in interdisciplinary research projects in a large multi-disciplinary research institution with regular career assessment. Our study is based on a direct survey with almost 1000 answers, as well as human resources statistics of the period 2015-2020. The survey scrutinizes certain critical parameters, in particular in terms of the research time spent on interdisciplinary projects, the original discipline and academic age of the respondents.

In this article interdisciplinarity is materialized by researchers who work together, from - and between - their disciplinary points of view, on a common object of study, in a coordinated, interactive way and with an integrative aim. This co-construction develops new and original contents and methods, which will in return nurture disciplines creating a fertile scientific feedback. The emergence of novel approaches at the interface of at least two disciplines can even ultimately be combined to form a new discipline (i.e. bio-informatics). This definition has to be compared with that of multi-disciplinarity which is, according to Darbellay (2018), a sequential process in which researchers of different disciplines work, from their own point of view, on a more or less shared object of study, in an independent and juxtaposed way.

The co-construction of an interdisciplinary project requires different phases such as the pre-problematization of the scientific question and the elaboration of the research device, the definition of the means of study and the methodological approaches to be implemented. Numerous exchanges are therefore required between the partners in order to be able to understand the other disciplines before the implementation of the project (i.e. understanding, vocabulary appropriation, common semantics). Moreover, it is necessary to ensure throughout the development of the project that it remains interdisciplinary to avoid a return to the disciplinary and to ensure that the research is nourished by the different scientific cultures of the partners of the project, which amounts to being able to establish bridges between the disciplines. The transfer of concepts, theories or methods from one discipline to another in order to generate new knowledge requires a constant dialogue between the project partners. These findings, have been partially reported before – either in a restrained thematic perimeter or based on a reduced number of researchers – (Darbellay et al., 2016; LERU, 2016; Bridle, 2018). They raise many questions, one of the most significant for researchers being the potential impact of their involvement in interdisciplinary projects on their careers. Indeed, the conduct of interdisciplinary projects in the frame of academic institutions, which are mainly organized along the lines of disciplinary research, can have an impact on the career path of researchers, especially the youngest ones, because of its singularities.

The first of these impacts concerns the different temporalities that are generally put forward between the development of disciplinary and interdisciplinary projects, the time considered to develop the

latter being generally considered longer (Darbellay et al., 2016; LERU, 2016). Another related issue concerns the valorization of data, in particular publication practices to disseminate interdisciplinary research results, as the way researchers publish their results both qualitatively (i.e. Impact Factor of the journals, citation impact) and quantitatively has consequences on their evaluation and career progression. Today, few studies exploring the relationship between interdisciplinarity and the citation impact have been published (Chen et al., 2021). To our knowledge, the link of interdisciplinarity with the researchers' career has only been studied rarely (Bridle, 2018), with a limited number of respondents and a certain geographical focus. As a consequence, not only the assessment of interdisciplinary careers but also, more generally, the evaluation of interdisciplinary projects must be questioned, as they cannot be judged according to the standards of a single discipline, nor as the sum of two (or more) disciplinary reviews. To date, there are very few clear indicators for evaluating interdisciplinary projects (Gleed & Marchant, 2016) and research on how to evaluate interdisciplinary projects is scarce (Huutoniemi et al., 2010). Although interdisciplinarity is growing, funding agencies, research bodies, and others still struggle to find practical ways to assess the quality of interdisciplinary science projects (Strang & McLeish, 2015; Lyall et al., 2011).

Actually, the impact of interdisciplinary research on the careers of scientists is difficult to assess objectively due to the lack of reference values and consolidated data. In order to better understand the impact that the engagement in an interdisciplinary project can have on the career development of researchers, we conducted a survey of CNRS scientists. CNRS is the largest public research institution in France, a multidisciplinary research organization structured in 10 topical institutes that cover more or less all fields of knowledge (biology, chemistry, ecology and environment, humanities and social sciences, systems engineering, physics, mathematics, nuclear, particle and high energy physics (NHEP), computer science, earth and universe sciences). The size of the institutes in terms of number of affiliated researchers is quite heterogeneous; the smallest communities correspond to mathematics and nuclear and particle physics. We are members of the Mission on Interdisciplinary Research and Transversal Actions (MITI) of the French National Center for Scientific Research (CNRS), created in 2011, which aims to encourage and support interdisciplinary research across all disciplines and between all institutes within CNRS.

Today, CNRS employs approximately 10 000 temporary and more than 12 000 permanent scientists throughout France, almost all of whom work in research laboratories run jointly with universities and/or other research organizations. These laboratories are often composed of several research teams addressing scientific subjects that can be either single-topic or different and multidisciplinary under the umbrella of a topical institute. Recruitment, career advancement and regular assessment of all permanent researchers is carried out by the "Comité National de la Recherche scientifique (CoNRS)", a national body affiliated to CNRS. CoNRS is divided in 41 disciplinary committees, (Figure 1). Each committee is affiliated to a given institute, reflecting the topical dispersion of disciplines and CNRS researchers. Besides disciplinary commissions, and to cover emerging and interdisciplinary thematic areas, four thematic interdisciplinary commissions (IDC), which focus on some particular aspects of interdisciplinarity have been created a few years ago (Figure 1).

The presence of a wide panel of disciplines, the large number of scientists in disciplinary and interdisciplinary projects, the availability of human resources data, make CNRS a unique field of study for interdisciplinary approaches, which can spontaneously emerge among researchers, but which are also encouraged through specific tools implemented by MITI. Moreover, the fact that every permanent scientist at CNRS is assessed on a 2.5-year term by a long-standing, well-structured body (CoNRS), allows not only to follow careers globally and individually, but also to identify strengths and weaknesses in the assessment process. In this context, the study of the impact of involvement in interdisciplinary projects on the careers of researchers within CNRS allows to provide some original insights in fundamental issues regarding interdisciplinarity in research careers.

To shed light on the relationship between interdisciplinary research and researchers' careers at the CNRS, the survey developed for this study assessed the following topics: (1) the scientific profile of the respondents, (2) research outputs as evaluation issues, (3) interdisciplinarity and researcher's career, and 4) relationship between interdisciplinarity and scientific identity. The originality of this study is based on the collection of individual opinions of researchers and its confrontation with figures from the human resources department, as the studies carried out until now were essentially documentary, and did not simultaneously question a significant number of scientists from very varied disciplinary fields.

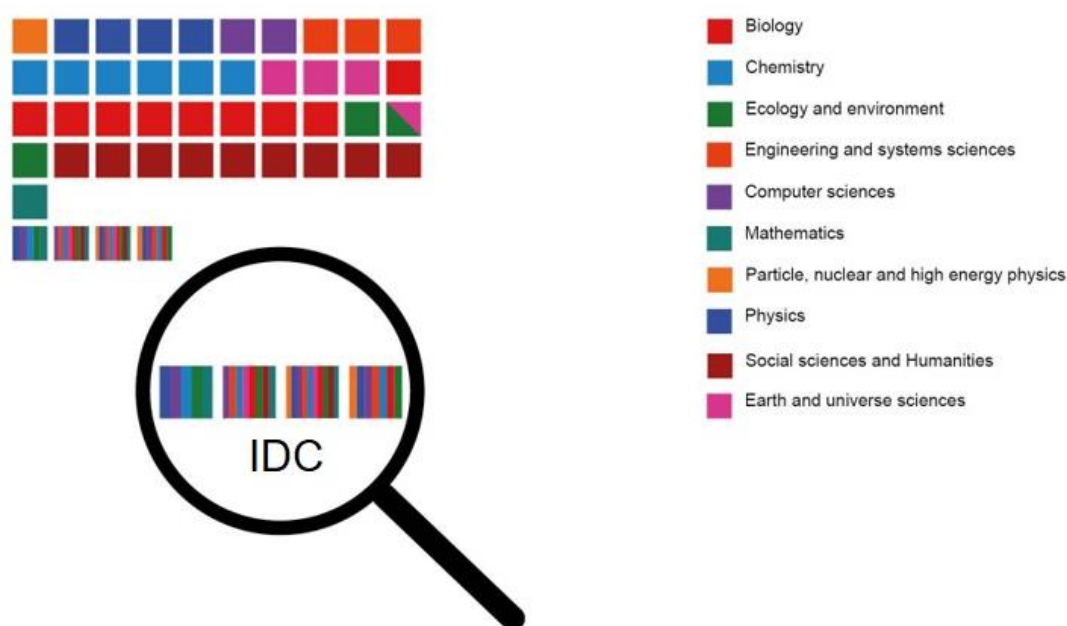


Figure 1 : Thematic organizational structure of CNRS. CNRS is structured in ten disciplinary institutes, the assessment by CoNRS is carried out in several topical committees for each institute plus 4 thematic interdisciplinary commissions (IDC)

2. Methods

This study is based on a survey, which – though open to the complete scientific community - was sent by email personally to a) researchers involved in interdisciplinary projects funded via dedicated calls by the MITI in the last fifteen years, b) researchers who have been recruited by CNRS with an interdisciplinary research project (in an IDC) since 2015, and c) CNRS researchers whose topical affiliation are not identical to the main identification of their laboratory (for example a physicist in a biology laboratory). These 3 groups are a pre-identification of researchers with a high probability of having been involved and or being involved today in interdisciplinary projects.

The survey contained a maximum of 130 questions depending on the respondents' profile, it was provided in French language. The English translation of the survey questions is fully accessible (Knoop, Galland, Vantard 2023). Completion of the survey took about 40 minutes. The data collected in this study were anonymized and researchers could optionally leave their contact details for potential interviews. The survey was developed through an iterative process of literature review, interviews with the chairs of the interdisciplinary commissions (ICD), and test runs among a small panel of researchers, to ensure the functionality and readability of the survey. To build the questionnaire, we used the Limesurvey software. The survey questions, which included mandatory and optional questions, with the possibility of adding free comments, focused on eliciting participant perspectives and experiences

with interdisciplinary research and training, as well as skills and support needed for a successful academic research career. Specifically, the questions were aimed at establishing their scientific profile, their perception of their personal assessment by the CoNRS committees, the evaluation of interdisciplinary projects (and disciplinary projects), and their personal position in disciplinary teams. In addition, participants were asked to express themselves on the obstacles and challenges related to interdisciplinary research.

Based on the CNRS structure, the researchers who responded to the survey were sorted into 12 groups: 10 groups corresponding to researchers who indicated a topical perimeter of one of the 10 institutes, one group corresponding to researchers that belong to a bi-disciplinary commission at the interface of Ecology and Environment and the Universe Science institutes (EE group), and finally one group corresponding to researchers that belong to the Interdisciplinarity Commissions (IDC group), (figure 1). This last group is considered to be involved in interdisciplinary research projects for 100% of their research time, and will serve in the following as reference group.

Responses to the survey questions were analyzed quantitatively using Excel software. We conducted several analyses to determine whether responses to quantitative questions varied by major disciplinary areas, time spent conducting interdisciplinary projects, and researcher's age.

3. Results

3.1. Metadata

970 answers to this survey have been received, which corresponds to a response rate of 33.9 % for the direct invitations to the survey, and 55.5% of the respondents accepted to be contacted individually. It should be noted that more than 200 responses were recorded within 48 hours of the opening of the survey, signaling an important mobilization on these questions. All disciplinary research fields are represented, although the number of respondents per field varies (Figure 2). 10.8% of the respondents are attached to the IDC group, 65.7% of which being recruited since 2015. 4.9% of respondents are part of the EE group.

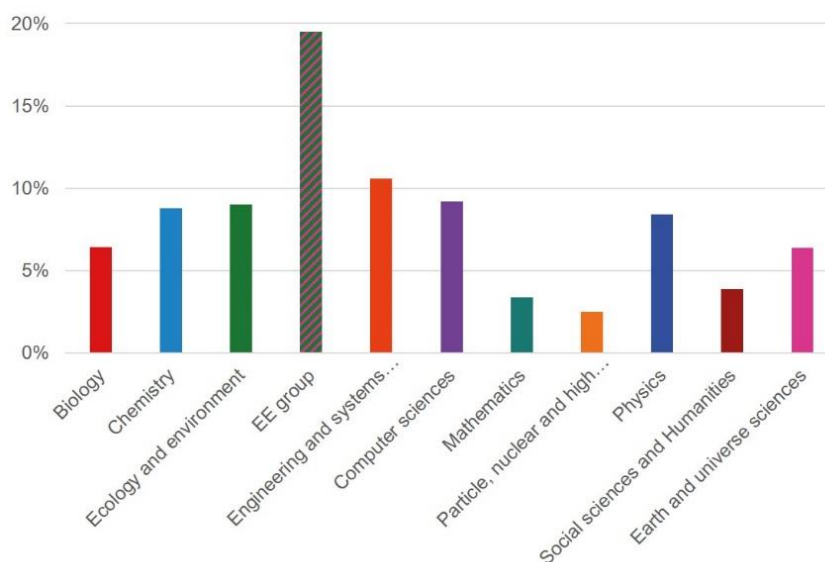


Figure 2 : Distribution by CNRS institute of respondents to the survey.

3.2. Respondent scientific profile

The first step of this study consisted in analyzing the general profile of the respondents such as their age, gender, scientific discipline, scientific background, and research time spent on interdisciplinary projects (see **Error! Reference source not found.**).

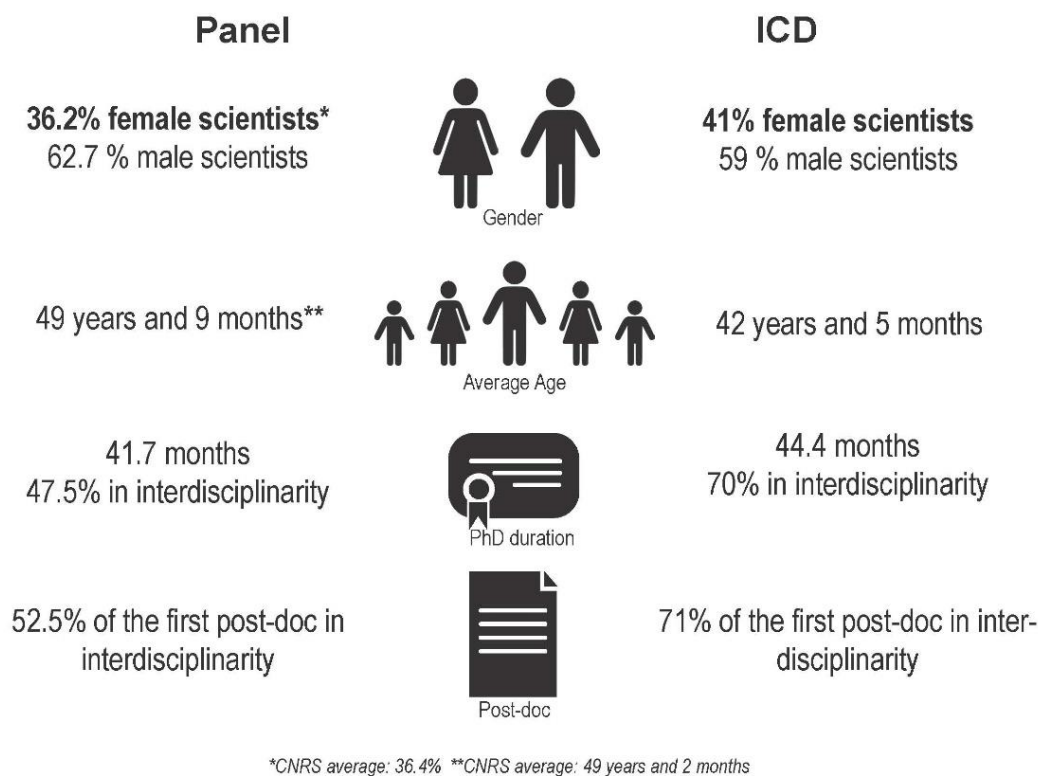


Figure 3 : Profile of respondents

While the average age of the panel and of the EE group is comparable to that of the CNRS researchers (49 years and 9 months), it is mechanically lower in the IDCs (42 years and 5 months) as we sent the survey specifically to researchers recruited by interdisciplinarity commissions since 2015, where they represent almost two-third of the group. Equally, the male-female ratio is comparable to the overall CNRS ratio (62.7% men, 36.2% women). Thus, the diversity of the respondent's profiles is representative of the researcher population working at CNRS.

In a second step, we analyzed the career path of the scientists before their recruitment to CNRS with a series of questions concerning the course of their thesis and their post-doctoral training periods (institution, duration, scientific topic, etc.), (Figure 3). The data collected show that the global average duration of the PhD was 41.7 months, a duration that is close to the theoretical length of 36 months for a PhD in France. For nearly half of the total panel (47.5%), the thesis research project was in an interdisciplinary context as well as for the first post-doctoral fellowship (52.5%). For the IDC group, the average length of the thesis is just slightly above but still comparable to that of the total panel (44.4 months) and it has to be noted that for nearly 70% of this group the PhD and/or the first post-doc were made on an interdisciplinary project. The number of post-doctoral internships completed by the IDC group before their recruitment to the CNRS and their duration are also comparable to that of the panel. It is on average 2 years for the panel and 1.9 years for the IDC group for an average duration of 2.2 years for the panel and 2.12 years for the IDC group. In correlation with these data, we observe that the number of years between the date of PhD completion and the date of recruitment at the CNRS is

also equivalent. If we analyze this number taking into account the age of the panel (the year of obtaining the thesis was chosen as a reference rather than the year of birth of the respondents), we observe that it has progressively increased over the last decades regardless of the individual time dedicated to interdisciplinarity.

As indicated above, scientists have been asked to quantify the fraction of their research time dedicated to interdisciplinary projects. We observe that 44.5% of the total respondents spent more than 75% of their time involved in interdisciplinary projects over the last ten years, this number being of 33.6 % without the IDC group that are considered spending 100%. The respondents who conducted their PhD project in an interdisciplinary context are more likely to be involved in interdisciplinary research projects for more than 75% of their time. The disciplines in which we find the greatest commitment in terms of time spent on interdisciplinarity are biology, chemistry, ecology and environment, and computer science. On the other hand, the time devoted to research in interdisciplinary projects is lowest in the field of NHEP. We do not note any significant difference according to gender and age. In conclusion, we observe a very clear correlation between the amount of time spent on interdisciplinary projects and having obtained a thesis and or done a first post-doc on an interdisciplinary project: respondents who worked on interdisciplinary projects when they were young researchers are the ones who spend the most time on interdisciplinary projects today. Moreover, if we observe that the time spent as a post-doc before being recruited as a scientist at the CNRS has increased over the years, it is not linked to the conduct of interdisciplinary projects both during the thesis and during the post-doctoral internship(s) suggesting that involvement in interdisciplinary projects as a thesis or postdoctoral fellow does not appear to be a hindrance to the early career of young researchers at CNRS.

3.3. Research outputs : evaluation issues

To address the impact of researchers' involvement in interdisciplinary projects on their careers, we have chosen at first to question them on the temporality for developing interdisciplinary projects followed by a series of questions on how they value the results of their research with a particular focus on publication practices. The answers to the questions were analyzed globally, by discipline, by age and by time dedicated to interdisciplinarity.

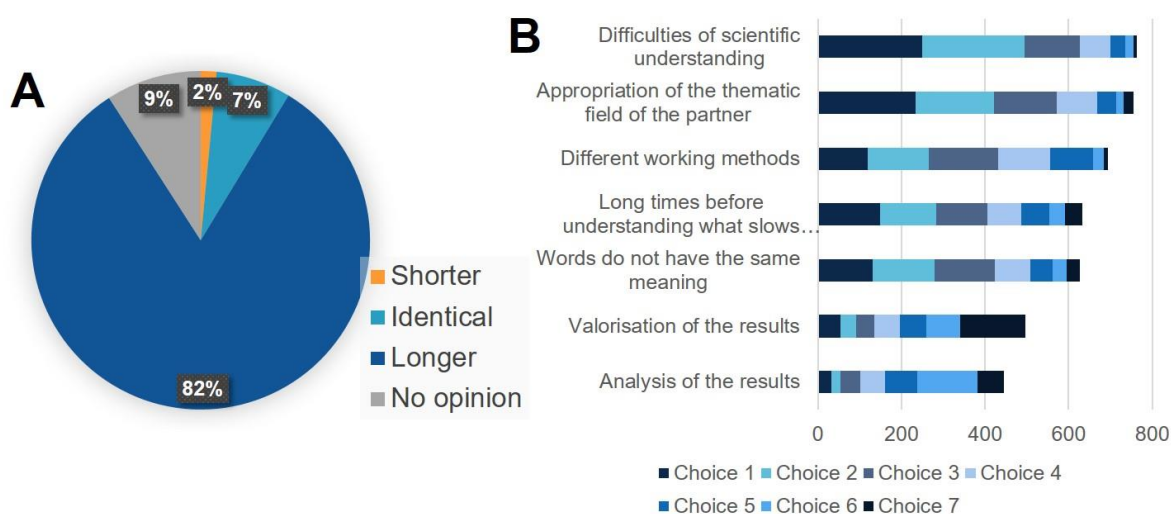


Figure 4 : Temporality to develop interdisciplinary projects. A. Panel answers to the question «Would you say that the time frame for developing interdisciplinary projects different from disciplinary projects? ». B. Reasons for longer duration of interdisciplinary projects (sorted choices).

It is well known, that the time required to develop an interdisciplinary research project as compared to a disciplinary research project, is a major issue (Darbellay et al., 2016; LERU, 2016; Bridle, 2018). Indeed, the researchers were almost unanimous, regardless of their discipline, age and time spent on interdisciplinary projects, to consider that the time needed to develop an interdisciplinary research project is longer than for disciplinary projects (75 to 90% depending on the discipline), see Figure 4. Unsurprisingly, the researchers who spend the most time on interdisciplinary projects are those who consider that their development takes longer than that of disciplinary projects. To explain these differences in the time frame, the majority of the panel put forward two major obstacles which are difficulties in scientific understanding and appropriation of the other's thematic field, followed by the need to understand each other, which slows down the implementation of the project. The development of a common language ("words do not have the same meaning"), different working methods, the valorization of results and finally varying result analysis are among the other factors which influence the duration of implementation (Figure 4B).

The dissemination of research data, generally in the form of publications or scientific reviews, is an integral part of the research process. It is also important for researcher's careers, their evaluation by their peers being essential as it plays a key role in their subsequent valorization. Although the CNRS has signed DORA (2012), publication criteria (i.e. impact factor, citation impact) are still largely part of the parameters used by CNRS commissions to evaluate researchers both at the time of their recruitment and for their career progression, even though their use is not encouraged. More generally, these parameter can be important in the evaluation of the research impact of scientists and academic institutions at the international level (i.e. international ranking), with differences depending on the discipline. In this context, we have chosen to address a series of questions on how scientists value the results of their interdisciplinary research compared to their disciplinary research, with a particular focus on publication practices.

At the general question "Do you think that your involvement in interdisciplinary projects changes the way you publish your work", 74% of the respondents, all disciplines included, answered yes and only 14% no, 12% having no opinion (Figure 1SA). This percentage grows with the time dedicated to interdisciplinarity (Figure 1SB). Regarding the type of journals that respondents target to publish their work (specialized or interdisciplinary), 37% of the panel claims to publish in equal proportion in disciplinary and interdisciplinary journals, 37% mostly in disciplinary journals, and 25% only in interdisciplinary journals (Figure 2S). However, these data must be qualified according to the disciplines, with the earth and universe sciences, NHEP, computer science, and mathematics publishing the most in a well-defined scientific discipline. If we consider the research time dedicated to interdisciplinarity, we can observe, that the more time is dedicated to interdisciplinary projects, the more the research results are valued in interdisciplinary journals. Researchers who devote less than 25% of their time to interdisciplinary projects are three times more likely to publish exclusively in disciplinary journals than researchers that are interdisciplinary to more than 75%. Scientists most involved in interdisciplinary projects publish the most in interdisciplinary journals while continuing to publish heavily in disciplinary journals. This latter fact suggests a maintained disciplinary anchorage.

In order to compare publication behavior between interdisciplinary and disciplinary work, we used three indicators: positioning as a co-author, journal impact factor, publication number (Figure 3S). Concerning the position as co-author, the majority of the respondents (60%) did not see any impact (Figure 3SA). Analysis of the answers by profile of the respondents shows a certain spread in disciplines: while mathematics, NHEP, and engineering, consider that this has little impact (79%, 69% and 67% respectively), only around 52 % of respondents in ecology and environment, and the humanities and social sciences share this opinion. We note that biology, which represents a field where the position of the author in publications is highly codified, responds practically like the average of the total panel: 57% do not see an impact on their positioning. The panel answers are more contrasted on the question of the impact factor (Figure 3SB), as 20% of the total panel consider that involvement in

interdisciplinary projects is a hindrance to publication in a journal with a high impact factor (i.e. biology and computer science), 35% think on the contrary that interdisciplinary research can be valorized in journals with a high impact factor, and 23% do not see any difference. It is worth noting that a significant number of respondents had no opinion (22%). All respondents state that the work resulting from interdisciplinary projects is published in the same way or in journals with higher visibility than results from disciplinary research (Figure 3SC). Finally, 48% of the panel believe that they publish fewer articles when engaged in interdisciplinary projects versus 15% who believe that they publish more, 21% finding no difference and 15% having no opinion. On these questions, no significant difference could be found as a function of the time dedicated to interdisciplinarity. These answers reveal that publishing results from interdisciplinary research tends to erode differences in publication behavior which exist between disciplines. They underline the fact, that scientometric approaches, maybe even more than in disciplinary publications, have to be used with great care.

On our question about the participation/invitations to scientific conferences to present the data resulting from interdisciplinarity, the collected answers reflect an almost random opinion: 38% of the panel do not perceive any difference with the disciplinary projects, while 38% do, and 27% have no opinion. The panel is more divided on the valorization of interdisciplinary research projects in terms of patents, obtaining contracts, and public exhibitions, and this for all disciplines, since 21% think it is easier, 22% more difficult, 22% the same, and 35% have no opinion.

In conclusion, the majority of the respondents feel that their participation in interdisciplinary projects changes the way they publish; many of them think that their interdisciplinary work is well valued but consider that they publish less than when they conduct disciplinary research. These responses are fully consistent with the widely shared feeling among respondents that interdisciplinary projects take longer to complete than disciplinary projects primarily because of difficulties in understanding the scientific field of the project's partner disciplines.

3.4. Interdisciplinary research: a challenge for researchers' careers?

The assessment of interdisciplinary research profiles and projects is an essential point of discussion when it comes to measuring its impact on the careers of researchers who are strongly committed to this path. Beyond the general questioning of the benefit and the limits of interdisciplinarity, the recognition of interdisciplinarity by evaluators and researchers (who are themselves evaluators), by research funding agencies and by research institutions remains a major issue. In order to collect the opinion of scientists on the evaluation of their interdisciplinary research projects by CNRS commissions, and their individual research and career advancement, several questions were developed.

Regarding evaluation criteria used to assess research projects, we first asked what scientists thought about their adaption to disciplinary projects, and the answer (Figure 5A) shows an overall satisfaction. Almost half of the panel thinks that these criteria are adequate, only 5% of respondents find them completely inadequate. For interdisciplinary projects, the opinion is a harsher, almost two-third of respondents (64%), regardless of the disciplines and the time dedicated to interdisciplinarity, think that these criteria are not very suitable (Figure 5B). Not surprisingly, researchers who spend the most time on interdisciplinary research are the most dissatisfied, researcher spending 75% to 100% of their research time on interdisciplinary projects are the most dissatisfied.

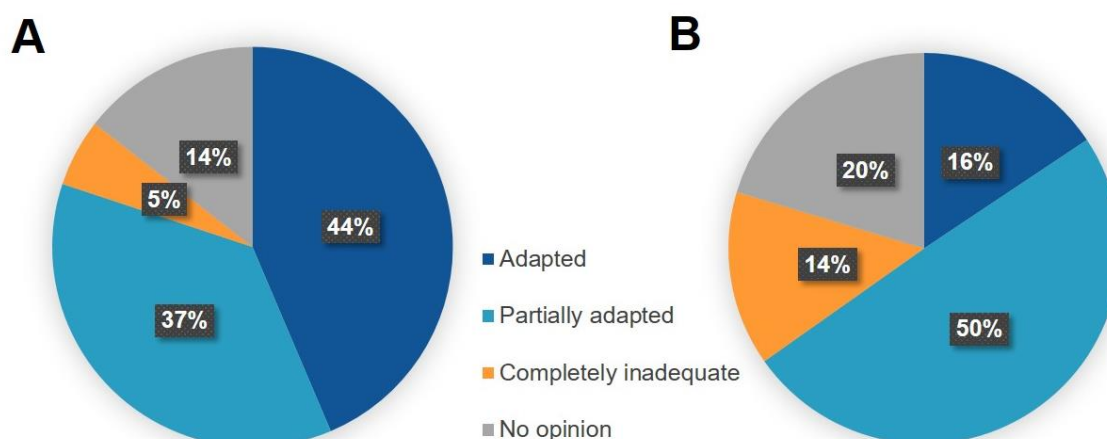


Figure 5 : Answer to a question about the adaption of assessment criteria in the (A) disciplinary and (B) interdisciplinary case (all respondents), (type your choice).

On the expectations of researchers regarding evaluation criteria half of the panel (54%) would like to see criteria specifically adapted to the conduct of interdisciplinary projects. Another third of panelists (32%) would like to keep evaluation criteria for disciplinary projects and see other criteria added (Figure 4SA). This is accompanied by the wish to train evaluators for assessing interdisciplinary projects, shared by 71% of the panel (Figure 4SB). Overall, half of the panel (50%) thinks that the quality criteria for evaluation of interdisciplinary research careers by the CNRS commissions should be rethought, only 9% are convinced of the opposite, and it has to be notice that a large fraction of the panel has no opinion (41%), (Figure 4SC). In fact, respondents are not very well aware of current evaluation criteria. Indeed, about a third think that the criteria used are the same for disciplinary and interdisciplinary careers, a third think they are different, and a third have no opinion. This (almost) random distribution, together with a large fraction of “no opinion” on the previous points, can be interpreted as an indication of ignorance of the evaluation criteria, which may not be sufficiently put forward by the CNRS commissions.

One of the main questions in a researcher’s career is the question of career development. We have asked the panel if they estimate that their involvement in interdisciplinary research has had an impact on their career advancement. 39% of the panel express a feeling of negative impact, while 27% see a positive impact, 19% being without opinion (Figure 6A). This negative impression is correlated with the amount of time dedicated to interdisciplinary projects (Figure 6B). It should be noted that the IDC group, which is evaluated by both interdisciplinary and disciplinary commissions, is less negative than the panel that devotes more than 75% of its time to interdisciplinarity, this one being evaluated only by a disciplinary committee. We also observe that this negative impression decreases with age, and that the younger scientists have no opinion about a putative acceleration effect on their career (Figure 6C). In line with this question, when ask what mechanisms should be promoted so that scientists engage in interdisciplinary projects, 70% of the panel answer that it is necessary to better value in their career their involvement in this way while they are divided equally into two groups with regard to an increase of calls and financing (50/50).

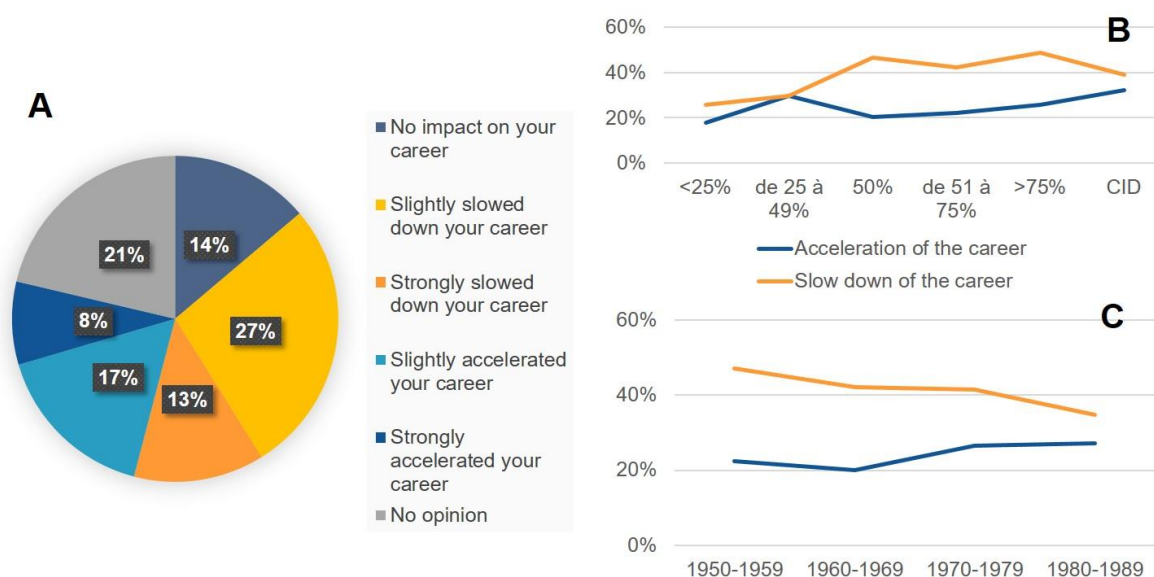


Figure 6 : Question on acceleration or deceleration of the career. **A.** Answer of the panel on «Do you think that your involvement in interdisciplinary projects has – (type your choice)? » **B.** Answer by time dedicated to interdisciplinary projects. **C.** Answer by age of the panel.

To go further, we have confronted these answers to the actual percentage of research fellows (CR) promoted to research directors (DR) in the category of researchers recruited in IDC. In 2019, the average age of promotion from CR to DR, lies between 41 and 50 years depending on the discipline and it can vary greatly between researchers in the same field (internal report CNRS: Social report and parity, 2019). The figures we have obtained on the DR advancement of IDC candidates fall entirely within this range, and therefore they do not allow to conclude that the involvement of researchers in interdisciplinary projects has a negative effect on their career development at CNRS.

It should be noted that the great dispersion observed in the age of promotions might be due in part to the choice of the indicator, which is the age of the scientists. Indeed, this age is not a relevant parameter because the scientific communities are very heterogeneous in their career paths, with a majority of researchers having an international origin or an international scientific background. In order to have a better vision of the progress of a researcher career, it would be more appropriate to express any career evolution with respect to the start of the PhD thesis, and the corresponding “academic age”.

In conclusion, all the data collected reveals a feeling of dissatisfaction among researchers regarding the evaluation of their interdisciplinary research projects (and, remarkably, a rather positive feeling for disciplinary research), and the impact on their career development. The respondents emphasized the need to reflect on the criteria for the assessment of interdisciplinary research, without however completely rejecting the criteria used for disciplinary research. The importance of training evaluators, in particular for interdisciplinarity, is underlined.

3.5. Interdisciplinary research: towards a new researcher identity?

As the need to develop interdisciplinary research becomes increasingly important to address complex scientific questions and societal and environmental problems, researchers are encouraged to become more involved in interdisciplinary research, and even to devote all or part of their career to it. However, as we have already seen, interdisciplinary research implies the implementation of new modes of

collaboration and project management, which may take time and represent a challenge in a context that is still very disciplinary, especially when the procedures for evaluating and promoting researchers are based on excellence in a single discipline.

In this context, we have tried to understand the motivations of scientists, especially young researchers who wish to establish their scientific reputation and career, to fully invest themselves in interdisciplinary research projects (Figure 7). We observe that for 60% of the respondents, the primary motivation is the need to respond to a problem requiring interdisciplinarity, then with decreasing priority come the interest for other disciplines, the opportunity to establish collaborations, obtaining of funding more easily, and finally an easier career progression. Thus, it is clear that the determining factor for engaging in interdisciplinarity is the need to solve problems that can only be addressed by crossing disciplines. Moreover, a large majority of the panel (59%), across all disciplinary fields, believes that the involvement in an interdisciplinary project is usually to be a long-term endeavor. Only a minority (13%) considers such an engagement for just the duration of a project.

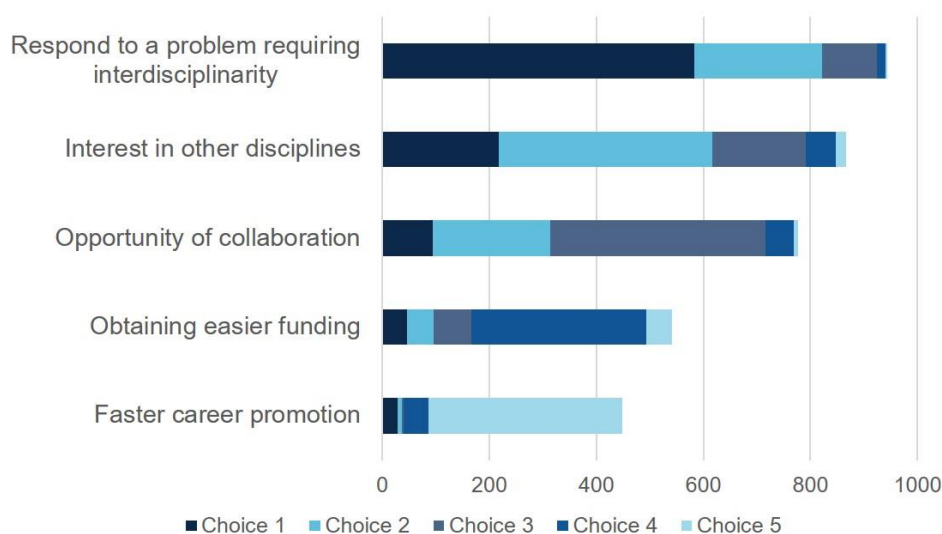


Figure 7 : Prioritized answers to the question « What are your main motivations to engage in an interdisciplinary project? (type your choice) »

To go further we analyzed the positioning of researchers involved in interdisciplinary projects within scientific communities: More than half of the panel (58%) thinks that interdisciplinary scientific communities have been formed in recent years, either established or emerging.

When researchers engage in an interdisciplinary project, three quarters of the panel consider that the anchoring in their disciplinary field is maintained and even amplified for 18% of them, this number being higher for the disciplines of ecology and environment and humanities and social sciences. These responses are coherent with the assertion by 60% of the panel that it is possible to build a disciplinary profile within an interdisciplinary community, although 31% are unsure about this. These results are in line with the fact that a large proportion of the panel publishes its results in disciplinary journals and participates in disciplinary conferences (see paragraph 1). On the other hand, 64% of the panel are convinced that it is possible to build an interdisciplinary profile within a disciplinary community.

Regarding the valorization of the research outputs, 41% of respondents believe that their involvement in interdisciplinary projects has allowed them to become more integrated in professional networks and only 18% think that it has not. However, three quarters of the panel think that the involvement in interdisciplinary projects when working in a research team that does not have a culture of interdisciplinarity can lead to isolation to different degrees. Finally, 88% of the total panel are convinced that involvement in interdisciplinary projects in the medium/long term can lead to an evolution of the scientific profile during the professional career, with slight variations depending on the discipline and the time spent in interdisciplinarity.

Globally, a very large majority of respondents think that involvement in interdisciplinary projects promotes the emergence of new working methods (86%), and new methods of knowledge production (87%), which will lead to a change in the way scientific questions are addressed (86%).

4. Discussion

Over the last decade, interdisciplinary research has increased in volume and importance in response to societal and environmental issues, as well as to increasingly complex scientific questions. This growing demand raises many questions, such as the evaluation process of projects, the methods of valuation of acquired data and results, or the positioning of researchers in an academic system still largely structured by disciplinary fields. This is an important issue, in particular where promotion and tenure procedures are mainly based on excellence in a single discipline, as it is the case for France and other countries. Indeed, interdisciplinary research is intrinsically more complex to organize and to assess than disciplinary research because it implies, by its very character, the formation of collaborative networks between researchers from different disciplines and often from different scientific cultures, to which are sometimes added strong partnerships with research organizations or private institutions and local authorities. Among the main specificities of interdisciplinary research is the longer time frame to develop research projects compared to disciplinary projects. Researchers find different explanations for this different temporality, such as difficulties in scientific understanding between several disciplines, agreement on definitions of key terms or elaboration of common working methods. In addition, the mutual dependence of researchers for the progress of their project and the complementarity of their expertise are essential elements that we must take into account and that underline the need for communication and frequent meetings between scientists on the content and progress of their work. These points have already been reported in several studies on interactions between researchers participating in international collaborative research projects or interdisciplinary projects (Hoch, et al., 2008; Van Noorden, 2015; Bark et al., 2016; Darbellay et al., 2016; Dusdall & Powell, 2021). They should lead us to reflect on the challenges that collaborative work between different disciplines represents for researchers, and consequently on the criteria to be considered for their evaluation.

Actually, the evaluation of researcher careers is essentially based on their scientific production, as these results are easily accessible. Our survey shows that the vast majority of respondents, regardless of discipline, age, and time spent on interdisciplinary projects, believe that they publish results from interdisciplinary projects differently than those from disciplinary projects. The quality of publications (i.e. impact factor of the journal, citation uptake) and, for example, the positioning as authors in publications, which are criteria generally taken into account to evaluate the work of researchers in some disciplines, and which reflect "authorship" between colleagues, are not considered in this study as a major difficulty by the survey respondents. In line with this, Van Noorden (2015) reports a generally higher citation impact for interdisciplinary research publications than for single discipline publications, but it takes longer to achieve this impact. On the contrary Millar (2013) reports that interdisciplinary research can lead to more publications, knowing that according to Porter et al. (2007) and Wang and Schneider (2020), the impact of interdisciplinary studies on scientific production by standard bibliometric methods remains unsatisfactory and difficult.

On the other hand, this study shows that all respondents to the survey, even those most involved in interdisciplinary projects, continue to publish in disciplinary journals and participate in disciplinary conferences along with publishing in interdisciplinary journals and participating in interdisciplinary

conferences. These data, in agreement with those collected by Darbellay et al, (2016) from researchers in the field of humanities and social sciences, indicate that disciplinary anchoring is maintained. We have identified four reasons for this practice, the first being the fact that the results obtained may be mainly disciplinary. The difficulty of finding journals whose editorial line is adapted to the publication of interdisciplinary work, is a major issue for many interdisciplinary projects. Moreover, scientists may wish to remain anchored in their disciplinary community, and they remain under the judgment of disciplinary commission, which may induce them to choose disciplinary publication means. In order to offer in the future new possibilities for the publication of interdisciplinary research, which should grow even more in the years to come, it would undoubtedly be desirable that more high-quality journals specialized on interdisciplinary research should develop.

Concerning the assessment process of interdisciplinary research, our study shows that researchers have a negative perception of the evaluation of their interdisciplinary research projects and consequently of their personal evaluation, whereas they express a feeling of relative satisfaction with the evaluation of their disciplinary projects. This feeling of inadequate evaluation expressed by the panel is experienced by 39% of them as an obstacle to their career development. Beyond the evaluation as such, the statement, which remains subjective, undoubtedly reflects a lack of recognition of the specificity of their research by their peers.

More generally, our data reinforce the statement that the evaluation of interdisciplinary research projects has not yet sufficiently adapted to their growing development (Black et al., 2016; Gleed and Marchant, 2016; LERU, 2016). Thus, defining new criteria to be added to or substituted for those used to evaluate disciplinary projects appears to be a necessity and will involve raising awareness and training evaluators (who are themselves evaluated by these same entities) as requested by the majority of our panel and described in various reports (Bark et al., 2016; Moore et al., 2018; Schrot et al., 2020). Interdisciplinary research produces other outcomes for example new research fields, or transverse structuring of communities. Risk-taking, the overall evaluation of the project and not by discipline (each evaluator evaluating the part corresponding to his or her discipline), the timeframe for developing the project, the dynamics that the project can create in terms of collective innovation, both through the implementation of new methods and through the social and cultural impact that it can produce, are all criteria that will have to be discussed and taken into account in evaluating interdisciplinarity projects and scientists involved in. Given the importance of interdisciplinarity today, scientific communities need to think about defining clear indicators to evaluate it, as disciplinary standards cannot be applied, knowing that research on how to evaluate interdisciplinary projects has been scarce so far (Huutoniemi et al., 2010; Bark et al., 2016).

In this context, we underline the importance of discussing the application of scientometric indicators that are commonly used to evaluate scientists and or their projects (i.e. San Francisco Declaration on Research Assessment, 2012; The Leiden Manifesto for research metrics, (Hicks et al., 2015)). Even more than for disciplinary research, quantitative measures used as the primary metric to compare the output of researchers are found to be deficient for multi- and inter-disciplinary research. If the practice of peer-reviewed publications is not to be questioned, it appears more and more important not to rely only on bibliographic criteria such as the impact factor (which is not a measure adapted for individual assessment) or the h-index to evaluate the scientific contribution' researchers in general, and in particular for those engaged in interdisciplinary research, such as for their recruitment or promotion decisions. The development of interdisciplinary research can thus accelerate the change in the researchers' evaluation practices, by focusing on the article scientific content rather than the journal in which it was published, and on its influence on policies or practices around societal issues, for example. Many academic research organizations, including CNRS, have recently signed the agreement drafted by the European Coalition for the Advanced Research Assessment (CoARA), (2022). This agreement, based on five major principles - quality, impact, diversity, inclusiveness, and collaboration – and by focusing on the evaluation of research organizations, research projects and individual

researchers, should be particularly important in the future for the interdisciplinary research evaluation as it will allow for greater recognition of its uniqueness compared to disciplinary research.

The dynamics and questions raised by interdisciplinary research, due to their diversity and singularity, are more complex to analyze and do not fit into the criteria commonly used to evaluate researchers. A necessary point would also be the training and evaluation of evaluators. Two disciplinary referees cannot make a fully adequate interdisciplinary review, even if they have different backgrounds and expertise. At the interface of disciplines, experts often do not fully understand the subject, and can only give a partial advice. The self-indication of the confidence level of their review (being expert/generalist/outsider on the topic) could already allow to weight different reviews of the same topic. Training evaluators on the assessment of interdisciplinary research would be an important step forward, as it could give additional tools to many disciplinary reviewers.

Without appropriate evaluation of interdisciplinary research, it will be experienced by researchers as a hindrance to their careers, particularly for early career researchers who are striving to have numerous high-level publications, in order to be tenured and recognized in a disciplinary field in the current system. Thus, researchers engaged in an interdisciplinary career path must have a disciplinary anchor in which they are recognized while at the same time being competent in one or more other disciplines in order to advance in their career. Through the answers of the researchers who responded to our survey, we can perceive the emergence of new working methods and new methods of knowledge production for the existing and future interdisciplinary communities, which will most certainly lead to an evolution of their profession as researchers. This evolution will necessarily be accompanied by new teaching practices (Kragt et al., 2016; LERU, 2016), and the dissemination of knowledge through a plurality of academic and non-academic formats. Already the commitment to interdisciplinary research leads scientists to become more involved in a dialogue with society in response to its growing demands.

Our study allowed us to collect in a single survey the opinions of scientists working in very different disciplinary fields (i.e. humanities and social sciences, physics, computer science, biology, ...) within the CNRS on the impact of their involvement in interdisciplinary projects on their career. Their answers provide us with factual data on this question, but also on their publication practices (i.e. dissemination of their results), and a strong insight into their perception of the evaluation criteria used by the CNRS both in the disciplinary and interdisciplinary commissions set up a few years ago (i.e. IDC).

We now need to increase our knowledge of these issues in order to deepen our understanding and to be able to make recommendations to a research organization such as the CNRS and, more generally, to the academic scientific community as to the changes and developments to be undertaken. We will have to rely on the input of scientists from all disciplinary fields, those from the humanities and social sciences being perhaps more questioned until now on these practices than scientists from the so-called hard sciences. The major issues to be addressed will be the reviewers' training in the specific characteristics of interdisciplinary research versus disciplinary research. This point is all the more critical as interdisciplinary research is expanding and mobilizes more and more scientists; it is also evolving rapidly. We will also have to question the real impact of interdisciplinary research' development on scientific practice and analyze the organizational issues that influence the success or failure of these projects. These studies will be developed by MITI, which, through its missions of supporting interdisciplinary research programs and managing competitive interdisciplinary programs within the CNRS, and its but also for all French research establishments, has the means to collect a great deal of indispensable data.

In conclusion, after having collected survey data and compared it to factual statistics, we have discussed the main specificities and issues encountered by scientists that choose to engage in interdisciplinary research projects. Based on these data, we are convinced that it is urgent to take action to foster interdisciplinary research and the engagement of scientists in interdisciplinary

projects. Our study leads us to identify several barriers, and in order to overcome these sticking points we make four proposals to support interdisciplinary research and researchers in the mean-term:

1 – develop high-quality interdisciplinary journals, which allow researchers to present their findings in the full context, without having to choose disciplinary subjects from their overall research project.

2 – redefine and enlarge assessment criteria used for the evaluation of interdisciplinary projects and or careers.

3 – weigh evaluation reports by taking into account the knowledge and expertise that the reviewer has of the overall interdisciplinary project or career.

4 – train evaluators on the specificity of interdisciplinary projects or careers.

These points need to be elaborated and discussed within the scientific community to be able to propose solutions, which should be as inclusive as possible to the different scenario of interdisciplinary research. Interdisciplinarity can offer novel and original approaches in science allowing insight into complex and multi-scale problems. We must create the fertile ecosystem for these approaches to continue to make important contributions.

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Author contributions

Conceptualization: MK, MV; Methodology: CG, MK, MV; Investigation: CG, MK, MV; Data curation: CG; Formal analysis: CG, MK, MV; Writing - original draft: MK, MV; Writing - review & editing: CG, MK, MV

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Data availability statement.

The full list of survey questions is available at <http://dx.doi.org/10.5281/zenodo.7806109>, all other quantitative data is available on request.

Competing interest

The authors have no competing interest to declare.

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SUPPLEMENTAL FIGURES

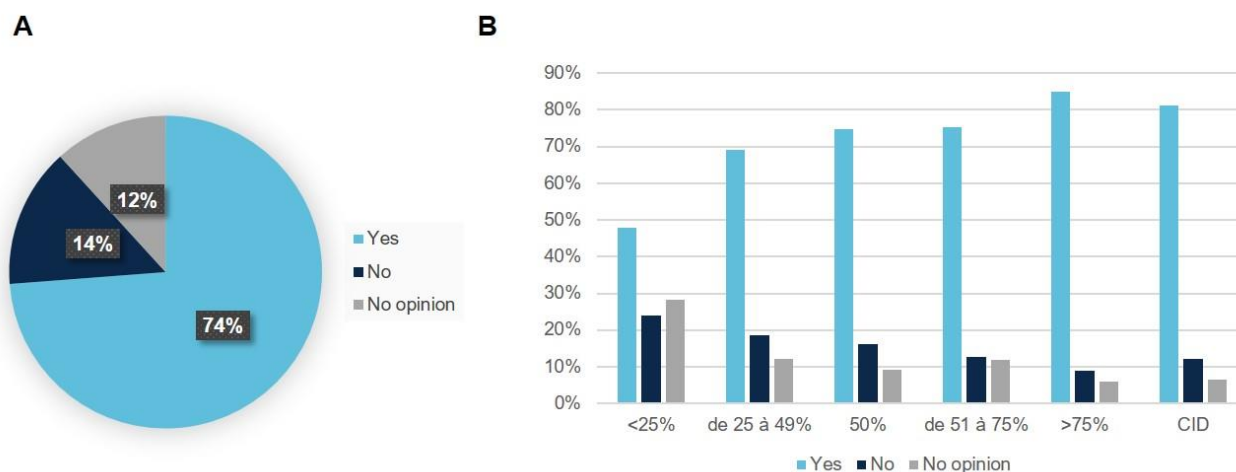


Figure 15. Answers to the question « Does your involvement in interdisciplinary projects change the way you publish your work (i.e publication frequency, journals)? ». **A.** Total panel; **B.** Total panel by time dedicated to interdisciplinary projects.

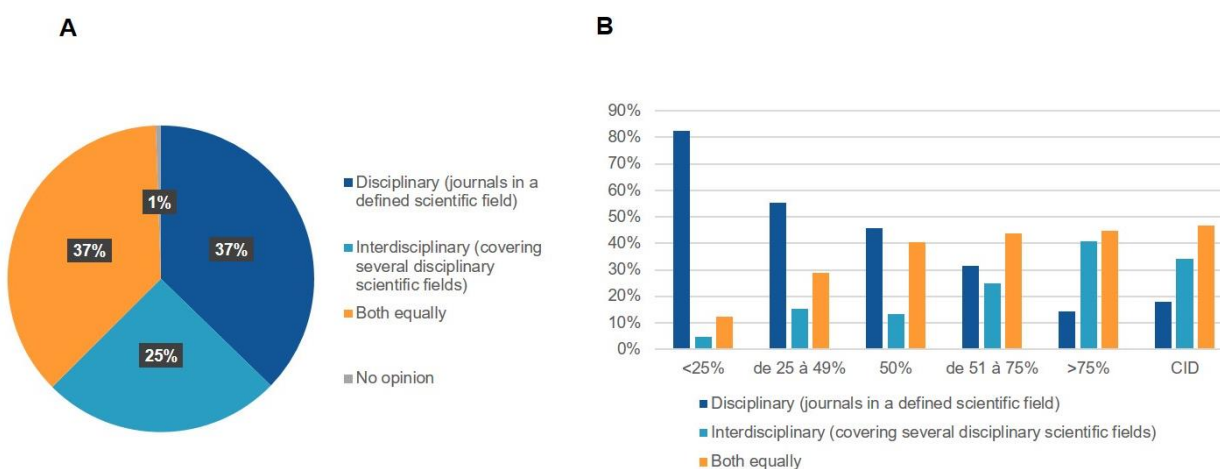


Figure 25. Answers to the question « Do you rather publish in journals: disciplinary, interdisciplinary, both equally? ». **A.** Total panel; **B.** Total panel by time dedicated to interdisciplinary projects.

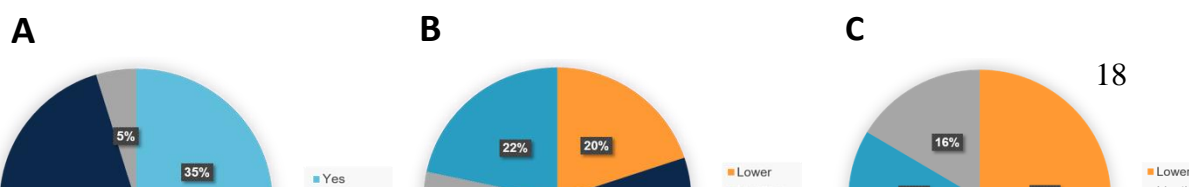


Figure 3S. Impact of involvement in interdisciplinary projects on: A. Perceived changes in the positioning as a co-author, B. Journal impact factors, C. Publication number

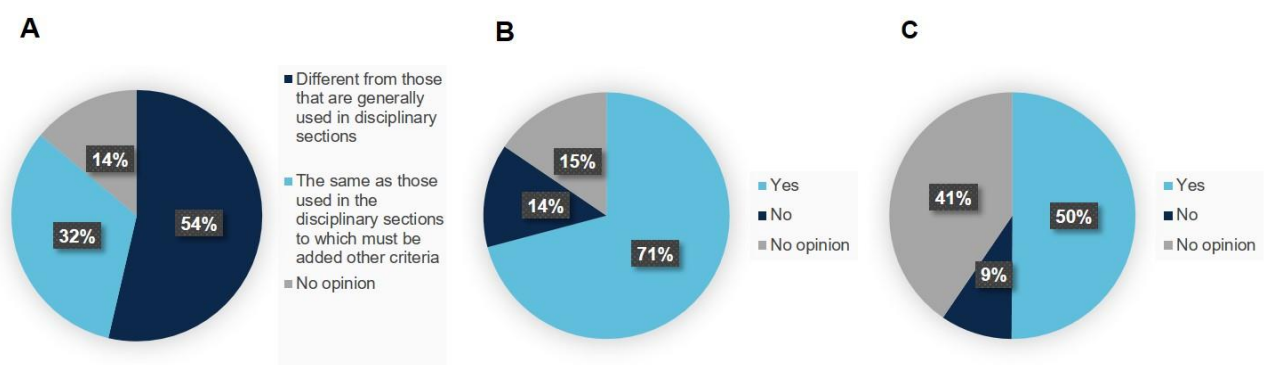


Figure 4S. Expectations in terms of evaluation criteria: answers to the following questions. A. "From your experience, do you think that the criteria to be taken into account to evaluate researchers engaged in interdisciplinarity should be - (tick all that apply)?" B. "Should evaluators be trained to evaluate interdisciplinarity (i.e CoNRS, National Agency for Research)?" C. "The quality criteria taken into account to evaluate an interdisciplinary research project by the CoNRS must be rethought?"