A Multiple-Perspective Analysis of Doctoral Interdisciplinarity

María del Carmen Calatrava Moreno*, Petra Kynčlová†, Hannes Werthner*
*Electronic Commerce Group
Institute of Software Technology and Interactive Systems
Vienna University of Technology
calatrava@ec.tuwien.ac.at
werthner@ec.tuwien.ac.at
†Institute of Statistics and Mathematical Methods in Economics
Vienna University of Technology
kynclova@statistik.tuwien.ac.at

Abstract—Interdisciplinary and assessment initiatives are two parallel educational paradigms that are being increasingly implemented in higher education institutions. Our study combines these two paradigms in order to assess the significance and performance of factors and processes that facilitate interdisciplinarity at the doctoral level. Using the 360-degree feedback methodology, we integrate the perspectives of different academic stakeholders in the assessment, namely students, post-doctoral researchers, professors, directors, visiting professors and research funding agencies. Therefore, this study not only provides a global assessment but also informative intermediate results, such as analyses on the alignment and discrepancies of stakeholders as well as the identification of priorities for improvement. This paper presents the development and implementation of this multiple-perspective assessment within an academic context and discusses the results of its application in a European faculty of computer science where several doctoral programs with different approaches to interdisciplinarity co-exist.

I. INTRODUCTION

Interdisciplinarity is receiving growing attention in the academic world. Doctoral students, as the youngest generation of researchers, and their doctoral programs are central to increasing the interdisciplinary research capacity of higher education institutions [1]. In Europe, new doctoral structures—alternatives to the traditional doctorate—are proliferating and many of them provide interdisciplinary training to doctoral students [2], [3]. These programs typically run in parallel to the traditional doctorate and have different admission and selection procedures, structure, and course curricula. They administer interdisciplinarity with different strategies such as interdisciplinary courses, joint curricula with other faculties and institutions, double-supervision in different fields, etc.

In an effort to assess educational practices, this study analyzes doctoral interdisciplinarity, which is increasingly viewed as a professional responsibility of higher education institutions [4]. It is conducted at a highly ranked faculty of a European university, in which six structured doctoral programs run in parallel to the traditional doctorate. It focuses on the field of computer science, where—in spite of its interdisciplinary origin and multiple applications—many areas conduct fundamental single-disciplinary research.

This analysis is the third part of a larger study on interdisciplinarity at the doctoral level conducted at this faculty. In the first part, we measured the interdisciplinarity of doctoral students based on a bibliometric analysis using the Rao-Stirling diversity index [5] and its interval of uncertainty [6]. For the second part, students who were the most interdisciplinary according to the diversity index were invited to semi-structured in-depth interviews to analyze the factors and processes that contributed to their interdisciplinary work [7]. In this third and latest part of the study, we analyze how the fulfillment and importance of doctoral interdisciplinarity is perceived not only by students, but also by other academic stakeholders (i.e., post-doctoral researchers, professors, program directors, faculty directors, visiting professors, and research funding agencies). We base our work on the 360-degree feedback methodology to integrate their opinions on the fulfillment and importance of interdisciplinary criteria at the doctoral level [8]. In this paper we explain the methodological modifications to this approach for its utilization in our study as well as its implementation. Then, we present the results and discuss the implications for education and research policies.

II. RELATED WORK

Assessment in higher education has been receiving ever-increasing attention over the past three decades. This has been motivated by the widespread view that teaching and researching can be informed and improved with insights on educational processes and outcomes [9], [10]. More recently, concern about accountability [11] has led to a growing array of quality measurement tools. Today, the field of assessment in higher education is characterized by its multiplicity of purposes, approaches, units of analysis, and stakeholders [12]. This broad array can also be applied to the assessment of interdisciplinary education and research.

Assessments of interdisciplinarity have been conducted with quite diverse focuses and goals. The qualities, processes, and influence of coursework and teaching programs [13], [14], research mentoring [15] and initiatives to facilitate students' interdisciplinarity such as collaborative learning [16], have

been analyzed to inform teaching and provide learning support. Other focuses include the certification of interdisciplinary research centers and programs [17], as well as the review of research policies [18], [19].

Given the variety of purposes of interdisciplinary assessments, it is natural that different approaches, both qualitative and quantitative, should be utilized. Mitrany and Stokols [20] present two main methodologic strategies for evaluating the transdisciplinary qualities and outcomes of doctoral training programs and dissertations. On the one hand, process measures include self-reports of the influence of coursework, research mentorship and scholarly exchanges along with one's intellectual values, attitudes and behaviors. On the other hand, product measures include external, objective appraisals of the transdisciplinary qualities of published papers, theses and dissertations. The most common method is the use of surveys [18], [21], [13] which has been used to examine both processes and products. Bibliometric methods have been used to quantitatively assess the extent of the interdisciplinarity of research centers and programs [22], [23]. These methods focus on the product of interdisciplinarity rather than on the process. They provide a measure of interdisciplinarity based on the integration of different disciplines in scientific publications via their references, keywords or co-authors. Another method based on scientific writing is proposed by Mitrany and Stokols [20]. They suggest a composite scale designed to measure the transdisciplinary qualities of doctoral dissertations. Their evaluation is done by independent reviewers that rate multiple dimensions of transdisciplinary integration and scope. In order to analyze processes, interviews as well as discussions and focus groups have been used to gain a deeper understanding of interdisciplinary experiences and processes [12], [24], [7]. Moreover, both qualitative and quantitative methods have also been combined to obtain complementary insights. For instance, a study on the Fifth Framework Program of the European Community for research [19] combines the input of discussions in workshops, a questionnaire and the analysis of case studies. Another example is the study on the promotion of interdisciplinarity by the Academy of Finland [25], which assessment is based on a qualitative analysis of research proposals, a survey and interviews. These methods are used to investigate different units of analysis from individuals to disciplinary communities/fields over groups of individuals and institutions. Therefore, assessments of interdisciplinarity might include a single kind of participant / respondent (e.g., students) or diverse stakeholders (e.g, faculty, students, states, research funding agencies, directors, etc.)

This wide range of different approaches in the literature about how to define indicators of interdisciplinarity is not surprising. A substantive assessment of interdisciplinarity is shaped by the variability of the goals, indicators, actors and available data. Within this broad landscape, our study focuses on the comparative assessment of the opinions of different academic stakeholders on interdisciplinary processes and factors that take place at a higher education institution. To our knowledge this is the first time that this kind of comparative

analysis is utilized at an institutional level in the literature of assessment of interdisciplinarity.

III. CONTEXT OF THE STUDY

This study was conducted in January 2016 at the faculty of computer science of a university ranked highly in this field. Since the adoption of the Bologna Declaration [26], this faculty has implemented six structured doctorate programs that run parallel to the existing traditional European doctorate program. In the following, we describe the main characteristics of the different programs of the faculty:

A. Traditional European program

The majority of doctoral students in the faculty are enrolled in this program. The admission and selection of students is loosely regulated. Individual professors manage the admission and selection process by selecting students to study with them, typically on a single-supervision basis. Students should earn a minimum of 18 course credits to graduate. Up until 2015 the program of studies had no compulsory courses, but students who enrolled after 2015 are now required to pass two fundamental courses equaling six course credits (e.g., philosophy of science and methodologies, career planning, research methods). The remaining courses are chosen by the student with the expectation that the chosen courses be related to the student's research area. Students are usually employed as university or project assistants funded by a third-party partner, or are self-funded.

B. Structured doctoral programs

These programs follow an Anglo-American doctoral model. There are published rules for application, selection and admission. They have structured curricula with general and subject-related courses and milestones.

1) Doctoral school: The doctoral school is a multiple-cohort structured program that covers all research areas of the faculty. This program aims to broaden students' knowledge across the different areas. Students are required to take introductory as well as advanced courses on different computer science areas, as well as fundamental and soft-skills courses. They are offered a three-year scholarship and are free to choose any topic in computer science that a professor of the faculty agrees to supervise. This program had 27 students at the time the survey was conducted.

2) Doctoral colleges: There are five doctoral colleges at the faculty. They are single-cohort programs that focus on specific topics. Each of these programs implements structural strategies to promote interdisciplinarity, such as co-organization by different faculties, collaboration with experts from different fields, courses in different disciplines and co-supervision of students. The doctoral colleges are funded as research projects and are therefore active for a limited time. They each have 10-30 students who are offered a 3-year position as project assistants. At the time when the survey was conducted there were 40 students enrolled in the five programs, which were at different stages: a couple of programs were about to finish,

others had been running for two to three years and one had been recently implemented.

IV. METHODOLOGY AND IMPLEMENTATION

We base our analysis on the 360-degree feedback methodology [8], also known as the 360-degree performance appraisal. In human resources or industrial psychology, this method is utilized by organizations to collect information about the practice and performance of an individual from different viewpoints. Its name stems from the fact that it solicits feedback from the *stakeholders* "around" the individual such as subordinates, peers, supervisors, customers, etc. Main advantages of this methodology include: (i) a multiple-perspective judgment that delivers a rounded portrait of the assessment; and (ii) increased validity due to the inclusion of the complementary opinions of stakeholders with different expertise.

Conceptual modifications of the 360-degree feedback methodology were made in order to adapt it to our context. Rather than evaluating individuals, we aim at assessing doctoral interdisciplinarity; thus, feedback is gathered from the following academic stakeholders: students, post-doctoral researchers, professors, doctoral program directors, faculty directors, visiting professors and research funding agencies.

We also introduced a methodological alteration to the 360-degree feedback by utilizing a double scale that not only assesses fulfillment of criteria but also their importance. Each criterion was evaluated with two questions, one evaluating its fulfillment (e.g., *To what extent... ?*) and the other assessing its importance (e.g., *How important is it... ?*). This double scale aims to provide information for effective resource allocation and adequate prioritization of actions for improvement.

Since the aim of this study is to assess doctoral interdisciplinarity, important factors and processes that contribute to the interdisciplinary development of doctoral students constituted the set of criteria to be assessed by the stakeholders. In the literature addressing interdisciplinary education, some works have listed qualities of interdisciplinary work [24] or the skills it requires and so, by implication, have outlined criteria for assessment, which range from goals of interdisciplinary education [27], [28] over cognitive skills [29], to processes and outcomes facilitating interdisciplinary research [30].

Our assessment is based on factors and processes involved in interdisciplinary research at the doctoral level. The criteria were selected based on the analysis of (i) the semi-structured interviews conducted in the second part of this study with interdisciplinary students who were identified using the Rao-Stirling diversity index [5], (ii) additional interviews with interdisciplinary professors also identified with the Rao-Stirling diversity index and (iii) a literature review.

The following criteria were selected:

1) OVERALL INTERDISCIPLINARITY: An assessment of the overall interdisciplinarity of the students' research.
2) WORK ENVIRONMENT: An interdisciplinary work environment is suggested by Huutoniemi [31] as a quality criterion to emphasize integration and synergy of disciplines, as it allows for interactions between disciplines [32]. Moreover, it has also been described as both a quality outcome and goal for interdisciplinary programs [33].
3) COURSES: Coursework distributed across disciplines and departments is a common strategy to promote interdisciplinarity among students [32]. It has been widely implemented both in the form of courses that integrate different disciplines [34], [20] and as an assemblage of several disciplinary courses [35].
4) METHODOLOGIES: The diversity of research methods in doctoral dissertations appears to be closely associated with its integration of disciplines [20]. Since single-disciplinarity is often tied to the use of certain methodologies [25], training in different methodologies has been suggested as one of the measures institutions should take in order to support the interdisciplinarity of their doctoral students [35].
5) COLLABORATION: Since complex real-world problems often require expertise across disciplines, collaboration with other disciplines is regarded as essential for interdisciplinary research. It has been described as a key factor in facilitating the exposure of doctoral students to multiple disciplinary perspectives as well as to encourage a broader approach integrating those perspectives within the dissertation study [20], and as a learning outcome of interdisciplinarity [33]. In the interviews conducted in the previous phase of this study, students also emphasized the necessity for collaboration with experts in other disciplines as part of an important process for conducting their interdisciplinary research [7].
6) CONTRIBUTION: Interdisciplinary contributions have been defined as enterprises in which some of the concepts and insights of one discipline contribute to the problems and theories of another [36]. These constitute the natural outcome of interdisciplinary research. However, as the amount of knowledge in any field continues to increase dramatically, it is increasingly difficult for doctoral students to make significant research contributions in more than one field [37].
7) CONCEPTUALIZATION: The degree to which students integrate previous literature in bridging theories and methods of two or more fields. Researchers achieve varying levels of integration in their work, from single disciplinary research where no integration occurs, through a moderate degree of integration, to a full integration of disciplines [38].
8) FUNDING: Many authors highlight the influence of funding structures on the prospects for interdisciplinary research [39], [40], [41]. Its influence at the doctoral level was confirmed in our previous qualitative analysis, in which the characteristics of different sources of funding exerted a strong influence on the students' interdisciplinary research [7].
9) SUPERVISION: Faculty members exercise enormous influence over students' doctoral studies. It is common for

doctoral students to work for and with their supervisor, their most important mentor, who not only advises students' course of study but also directs their research. The supervisor's earlier research and current research interests provide the intellectual foundation for the student's dissertation [37]. In the interviews conducted in the second part of this study, both students and faculty members discussed the important role of supervision in facilitating interdisciplinary research [7].

10) CO-SUPERVISION: Interdisciplinary research programs often encourage co-supervision from experts in different fields [42], [43]. Mitrany and Stokols [20] found striking differences in an analysis of the integration of disciplines that compared students receiving supervision in a single-field with students receiving supervision from professors in different departments. Moreover, in our prior qualitative study, we observed that truly interdisciplinary students often sought dual supervision in order to complement the expertise of their main supervisor [7].

These criteria were evaluated by the stakeholders through a series of survey questions. All stakeholders evaluated the importance of *all* criteria. However, not all stakeholders had the knowledge to assess the fulfillment of the criteria. For example, external stakeholders (e.g., research funding agencies or visiting professors) might not have enough knowledge to assess the fulfillment of the criteria. Therefore, each group of stakeholders evaluated a set of criteria on which they could provide feedback as shown in Figure 1.

Additionally, students also assessed the interdisciplinary antecedents that shaped their intellectual orientation prior to the beginning of their doctoral studies. According to our prior qualitative analysis of interviews with students, interdisciplinary research depends upon far more than the presence of interdisciplinary higher education structures and strategies. The following predisposing variables were identified [7] and only students assessed them in the survey:

- VALUES. We refer to interdisciplinary values as described by Stokols [44]: "The principles that predispose the individual towards acquiring a broad understanding of complex research and societal problems and translating integrative insights about them into practical solutions".
- MOTIVATION. We draw upon the self-determination theory to describe it as a continuum between amotivation and intrinsic motivation, where the former involves having no intention to conduct interdisciplinary research and the latter describes an individual motivated by interest in the interdisciplinary topic itself [45].
- PREVIOUS SKILLS AND KNOWLEDGE. Exposure to multiple learning environments, mentors and research settings that shape the intellectual orientation of a scholar [44].

At the beginning of 2016, stakeholders were invited via email to answer the online survey [46]. The introduction to the survey included indications that aimed to obtain a higher quality of participants' responses. First, since there is an extensive theology around the differences between inter- ,
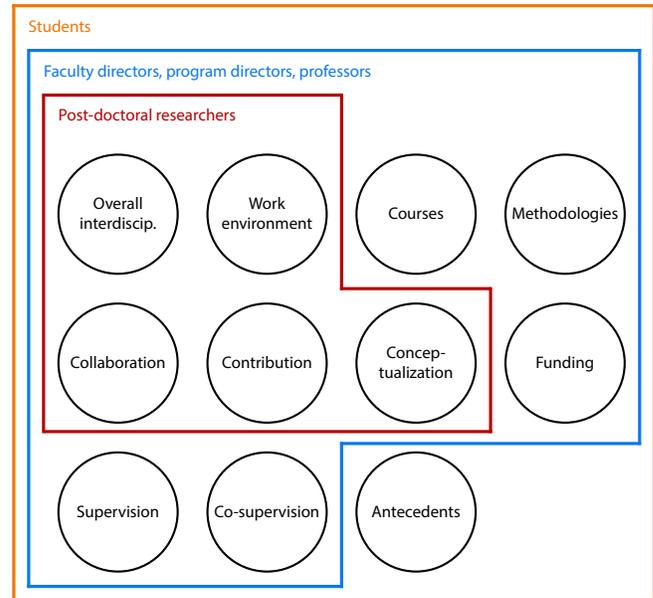

Fig. 1. Interdisciplinary criteria. Different stakeholder groups assess the fulfillment of the criteria comprised in squares.

trans- and multi- disciplinary research, each with its own shade of meaning, we provided our respondents with a simplified definition of *interdisciplinary research*. We used this term to describe research where two or more disciplines work together and quoted a definition provided by Land [47]. Second, respondents were asked to provide their most objective answers. We explicitly stated that this study makes no assumption that interdisciplinary research is better or more valuable than other types of research.

The first part of the survey consisted of demographic questions that allowed us to categorize respondents into stakeholder groups, areas of expertise in computer science, and doctoral programs in the case of student respondents. The following questions regarding the set of criteria were formulated slightly different for each stakeholder group. For instance, regarding the criterion OVERALL INTERDISCIPLINARITY students were asked to assess the interdisciplinarity of their doctoral research, post-doctoral researchers assessed the interdisciplinarity of the doctoral students in their research group, professors assessed the interdisciplinarity of the research conducted by students they supervise, and faculty directors assessed the interdisciplinarity of the doctoral students of the faculty as a whole. Each question was rated using a 4-point Likert scale in order to avoid neutral answers [48], with one point indicating the lowest interdisciplinarity rating, and four points indicating the highest. A total of 107 individuals responded (see Table I) and their responses were analyzed using statistical methods. All tests were performed with a 95% confidence level. Additionally, whenever possible all the assumptions of the corresponding tests were verified.

Stakeholder group	Respondents (Population)	Doctorate program	Respondents (Population)
Students	44 (211)	Traditional	23 (138)
Post-docs	11 (99)	Doctoral school	12 (27)
Professors	25 (53)	Doctoral college 1	1 (1)
Program directors	1 (5)	Doctoral college 2	4 (30)
Faculty directors	3 (3)	Doctoral college 3	1 (8)
Visiting professors	12 (28)	Doctoral college 4	2 (2)
Funding agencies	11 (58)	Doctoral college 5	1 (5)

V. RESULTS

The 360-degree methodology allows for the analysis of the data from different perspectives (i.e., per criteria, doctoral program, research area and stakeholder group). In this paper, we focus on the analysis of stakeholder groups and discuss the results of the assessment of those groups with a higher response rate (i.e., students, professors, faculty directors and external individuals). Additionally, we briefly discuss the results of the analysis of criteria and doctoral programs. All results presented in this section have been transformed to the interval [0,1].

A. Interdisciplinary criteria

In general, the fulfillment and importance of OVERALL IN-TERDISCIPLINARITY as well as the rest of the interdisciplinary criteria are very moderate (see Table II). METHODOLOGIES is the most fulfilled and most important criterion, not only on average for all respondents but also for each stakeholder group. The least fulfilled is CO-SUPERVISION and the criterion considered least important is COURSES.

The influence of doctoral policies and faculty structures can be observed in the data, as in the case of the low fulfillment of CO-SUPERVISION, which could be explained by the fact that none of the doctoral programs enforce double-supervision from experts in different fields. Nevertheless, this would not be a priority for improvement in the context of this faculty as it is considered one of the least important criteria for both faculty stakeholders as well as external stakeholders. The low fulfillment of WORK ENVIRONMENT might relate to the fact that the university where this study was conducted is not a campus university but a multi-site where the different faculties are situated in designated buildings located at various locations around the city.

B. Stakeholder groups

We conducted a comparative analysis of responses from individuals in different stakeholder groups.

In general, doctoral training within the faculty seems to facilitate interdisciplinarity for those stakeholders who consider it important. Faculty stakeholders (i.e., students, post-doctoral researchers, professors) for whom interdisciplinary doctoral research is of a high priority are more likely to see it realized. This can be observed from the survey results

for fulfillment and importance of the criterion OVERALL IN-TERDISCIPLINARITY, which shows a very significant positive correlation coefficient of 0.63 (see Figure 2). It is important to note that similar correlations exist between fulfillment and importance for OVERALL INTERDISCIPLINARITY as assessed by students, post-docs and professors.
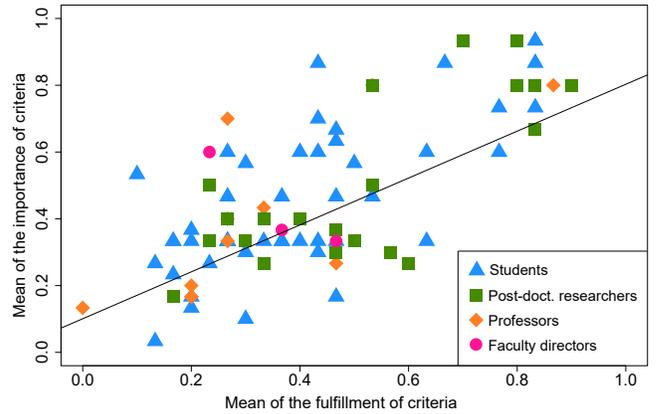

Fig. 2. Mean of fulfillment and importance of the criteria. Each point represents the assessment of a respondent.

Table III contains the aggregated assessment of all criteria for each stakeholder group. All stakeholder groups have a rather moderate opinion on the fulfillment and importance of the interdisciplinary criteria. Professors believe interdisciplinary criteria to be more fulfilled and important. Their opinion contrasts with the immediately higher and lower hierarchical groups in the faculty—faculty directors and post-doctoral researchers—whose assessment of both fulfillment and importance of all criteria is lower on average. Interestingly, professors are also the only stakeholder group who assessed the fulfillment of the criteria higher than their importance, which contrasts again with faculty directors and post-doctoral researchers whose assessment presents the largest difference between average fulfillment and importance.

In the following, we provide an insight on results that stand out for each of the stakeholder groups with the highest response rate.

1) Students: Students' assessment of fulfillment and importance of the criterion OVERALL INTERDISCIPLINARITY

Criteria	Estimated mean		Std. error	
	fulfillment	importance	fulfillment	importance
OVERALL INTERDISCIPLINARITY	0.435	0.466	0.035	0.030
WORK ENVIRONMENT	0.310	0.485	0.029	0.033
COURSES	0.414	0.392	0.036	0.027
METHODOLOGIES	0.581	0.633	0.028	0.033
COLLABORATION	0.467	0.497	0.033	0.032
CONTRIBUTION	0.392	0.370	0.033	0.027
CONCEPTUALIZATION	0.482	0.386	0.035	0.029
FUNDING	0.423	0.515	0.038	0.034
SUPERVISION	0.545	0.463	0.041	0.032
CO-SUPERVISION	0.270	0.404	0.035	0.029

Stakeholder	Mean		Std. error	
group	fulfillment	importance	fulfillment	importance
Students	0.397	0.449	0.01539	0.01503
Post-docs	0.327	0.400	0.03487	0.03378
Professors	0.524	0.512	0.01981	0.02098
Faculty direct.	0.356	0.433	0.03115	0.04749
Visiting profs.	–	0.461	–	0.02919
Funding ag.	–	0.470	–	0.03283

Fig. 3. Matrix of Spearman correlations of students' assessment of their antecedents, as well as fulfillment and importance of the rest of criteria.

are comparable (0.4 and 0.42). Moreover, these two variables show a very significant positive correlation (0.61).

One of the results of our previous qualitative study [7] based on interviews with students is that funding for interdisciplinarity constitutes a very influential factor that plays an important role in facilitating interdisciplinarity at the doctoral level. According to the results of this survey, students consider appropriate funding for interdisciplinary research to be the second most important requirement for conducting research of this kind. A striking observation from the data is that the fulfillment of appropriate funding does not correlate with any other fulfillment and importance criteria (see Figure 3). This indicates that the appropriateness of the funding provided to doctoral students for conducting interdisciplinary research does not seem to have any relation with the fulfillment and importance of other criteria. The missing correlations with the fulfillment and importance of OVERALL INTERDISCI-PLINARITY illustrate this discrepancy, which is also present in the assessment of professors. Another disconnection with the appropriateness of funding is also indicated by the missing correlation with the importance of the same criterion. Again, this lack of correlation could also be found in responses obtained from professors. Further explanatory research would be necessary to explain this issue. For instance, it would be important to investigate whether doctoral students are funded with means not tailored to the level of interdisciplinarity that
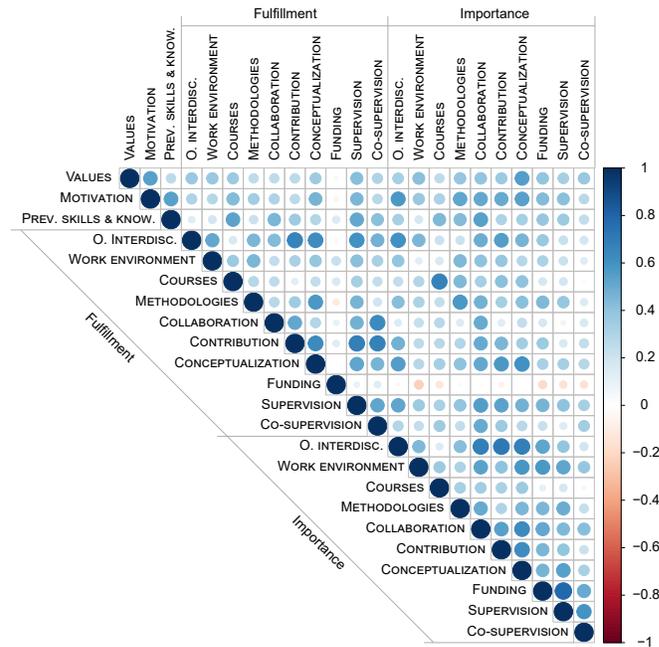
their research necessitates, or whether research funding is not sufficiently controllable by the applicants to match the interdisciplinarity or single-interdisciplinarity of their research.

Another interesting result from students' responses is the relation of the fulfillment and the importance of taking courses in different disciplines. The criterion COURSES shows a very significant positive correlation (0.69) between fulfillment and importance. This would indicate that, to a large extent, students take courses that fit the interdisciplinarity or single-interdisciplinarity of their research. This result does not only apply to students in the traditional program who have greater freedom to choose any course, but also to students in the structured programs who follow a specific course curriculum.

Moreover, we analyzed whether single-disciplinary and interdisciplinary students assessed the fulfillment and impor-

tance of criteria in a different way from each other. We used the fulfillment assessment of OVERALL INTERDISCIPLINAR-ITY to separate students into two groups: single-disciplinary (1-2 points on the Likert scale) and interdisciplinary (3-4 points). The number of students in the single-disciplinary group was 37, with 8 in the interdisciplinary group.

We used the one-sample Wilcoxon signed-ranked test [49] to test differences between the two groups. The tested null hypothesis assumed that the median fulfillment of the criteria assessed by interdisciplinary students is equal to the median fulfillment assessed by all students. The alternative hypothesis supposed that the fulfillment assessed by interdisciplinary students is greater than the median fulfillment of all students. Based on the results of this test (see Table IV) the null hypothesis is rejected for the criteria COLLABORATION, CONCEPTU-ALIZATION, SUPERVISION and CO-SUPERVISION. Thus these criteria represent the potential criteria where the fulfillment of interdisciplinary students is considered to be higher than for all students.

Criteria (fulfillment)	p-value
WORK ENVIRONMENT	0.17
COURSES	0.10
METHODOLOGIES	0.07
COLLABORATION	**0.02**
CONTRIBUTION	**0.01**
CONCEPTUALIZATION	**0.01**
FUNDING	0.12
SUPERVISION	**0.02**
CO-SUPERVISION	**0.02**

Interesting findings can be observed in Table V, which contains the results of the Wilcoxon test to check whether the median assessment of the importance of criteria is equal for both groups. The alternative hypothesis assumes that the median assessment of importance of single-disciplinary students is lower than the median assessment of all students. The null hypothesis is rejected only in the case of the criterion CONTRIBUTION. This indicates that this criterion is the only one that is considered less important by single-disciplinary students. Therefore, we assume that single-disciplinary students do not consider the rest of the criteria less important.

2) Professors: Their assessment of the fulfillment of OVERALL INTERDISCIPLINARITY is the highest of all stake-holder groups (0.56) and, in general, they also give more importance to the set of criteria than the rest of the stakeholder groups give. Professors who consider doctoral interdisciplinar-ity important are likely to have students also conducting in-terdisciplinary research. This is indicated by a very significant high correlation coefficient between their assessment of the fulfillment and the importance of OVERALL INTERDISCI-PLINARITY (0.74). In other words, there is a strong positive re-

Criteria (importance)	p-value
OVERALL INTERDISCIPLINARITY	0.71
WORK ENVIRONMENT	0.76
COURSES	0.96
METHODOLOGIES	1.00
COLLABORATION	0.98
CONTRIBUTION	**0.01**
CONCEPTUALIZATION	0.60
FUNDING	1.00
SUPERVISION	0.98
CO-SUPERVISION	0.96

lation between the interdisciplinarity of their students and their opinion on the importance of interdisciplinarity at the doctoral level. A similar correlation between the fulfillment and the importance of OVERALL INTERDISCIPLINARITY could also be observed in the assessment of doctoral students. In their case, the correlation coefficient is only a bit lower (0.61). A possible interpretation of this result could be that students have fewer opportunities to conduct interdisciplinary research than professors so when they consider it important. However, further explanatory research should be conducted in order to confirm this theory.

The data also suggest that professors who find additional supervision from other disciplines important are more likely to co-supervise their students together with experts from other fields. However, students are not as likely to have additional supervision from other disciplines even when they consider it important. This fact is indicated by the correlations of the fulfillment and importance of CO-SUPERVISION of professors and students. While professors present a very significant correlation of 0.74, for students it is just 0.34. Further ex-planatory research could investigate if this dissonance could be mitigated with discussions between supervisors and students about the need for additional supervision from another field. Since professors seem to have a better possibility of achieving co-supervision when they deem it important, students could benefit from communicating their need for feedback from other disciplines to their supervisors.

Another interesting finding is that professors on average, in contrast to other stakeholder groups, consider COLLABORA-TION rather important (0.61). It is their second most important criterion after METHODOLOGIES. Since supervision from an expert in a different field could be regarded as one of the most intense forms of collaboration for a doctoral student, it is interesting to observe that professors' assessment of the importance of CO-SUPERVISION (0.44) is comparably lower than their opinion on the importance of COLLABORATION. A similar difference between the importance of these two criteria could also be observed in the assessment of post-doctoral researchers.

Further analysis of the importance of COLLABORATION for professors indicates discrepancies with the faculty directors, who regard this criterion considerably less important (0.33) than professors do. Moreover, the correlation between the fulfillment and the importance of such a criterion for professors is just 0.52. This indicates that professors who think that collaboration with experts in other disciplines is important at the doctoral level do not necessarily see it fulfilled in the research of their doctoral students. As mentioned above, COLLABORATION is one of the most important criterion for professors. Therefore, such a discrepancy would merit further communication between professors and faculty directors in order to plan strategies to facilitate collaboration with other fields.

3) Faculty directors: Although each of the three faculty directors is critical of the fulfillment of OVERALL INTERDISCIPLINARITY (0.33), they do consider it important (0.78). However, the level of its importance contrasts with the level of importance they give to the rest of the criteria, which is considerably lower. Faculty directors show remarkable consensus in their assessment. While the standard deviation of the assessment of other stakeholders ranges between 0.26 and 0.31 in the assessment of fulfillment, and between 0.31 and 0.33 in the assessment of importance, the standard deviation of the faculty directors is just 0.14 in the assessment of fulfillment and 0.17 in importance.

In their opinion, only WORK ENVIRONMENT and CO-SUPERVISION are moderately important (0.56), while the rest of the criteria have low importance (0.33) for each of the three members. A qualitative study on the opinions of faculty directors would be necessary to explain their low assessment on the importance of the interdisciplinary criteria and to determine if there are any other important criteria that should be included in future assessments.

As mentioned in Section III-A, last year the course curricula of the traditional program was changed to provide more comprehensive doctoral training on research methodologies. In spite of this, the fulfillment of METHODOLOGIES is, in their opinion, still rather low (0.33) in comparison with the assessment of students and professors (0.58 and 0.61, respectively). This discordance is especially important because this criterion is the most important in the opinion of all stakeholder groups on average. Therefore, future policy changes regarding doctoral training in methodologies should be analyzed and evaluated prior to their implementation, as more emphasis on training in research methodologies could be considered superfluous by other stakeholder groups in the faculty who already see it being somewhat fulfilled.

4) External stakeholders: Visiting professors and research funding agencies share similar opinions on the importance of criteria. Their assessment on the importance of OVERALL INTERDISCIPLINARITY is very similar (visiting professors: 0.44; funding agencies: 0.42). Both groups identified METHODOLOGIES as the most important criterion (0.67 and 0.73, respectively), followed by WORK ENVIRONMENT (0.56 and 0.67, resp.). Moreover, they also assessed CONCEPTUALIZATION

(0.36 and 0.33, resp.) and COURSES (0.36 and 0.36, resp.) as the least important criteria.

C. Students' antecedents

In order to quantitatively evaluate the influence of the antecedents identified in our previous study (see section IV), we tested whether the fulfillment and importance of OVERALL INTERDISCIPLIANRITY is greater for students with higher interdisciplinary antecedents. For each antecedent, we divided students into two groups according to their assessment: low (1-2 points on the Likert scale) or high (3-4 points). The number of participants assigned to each group can be observed in Table VI. The one-sample Wilcoxon signed-ranked test [49] was used again to test hypotheses on the fulfillment and importance of the different criteria.

TABLE VI
NUMBER OF STUDENTS WITH LOW AND HIGH INTERDISCIPLINARY ANTECEDENTS.

Antecedents	Number of students	
	Low (1-2 points)	High (3-4 points)
VALUES	22	23
MOTIVATION	27	18
PREVIOUS SKILLS AND KNOWLEDGE	26	19

The null hypothesis assumed that the median fulfillment assessment of students with high interdisciplinary antecedents is equal to the median fulfillment assessment of all students. The alternative assumed that the assessment of students with interdisciplinary antecedents is greater than the median assessment of all students. According to the results of Table VII, the null hypothesis is rejected for the criteria OVERALL INTERDISCIPLINARITY, COURSES, CONCEPTUALIZATION and CO-SUPERVISION. This indicates that students with a higher number of interdisciplinary antecedents are likely to have a higher fulfillment of these criteria.

We also tested whether the median importance assessment of students with high interdisciplinary antecedents is equal to the median importance assessment of all students. This time the alternative hypothesis assumed that median importance assessment of students with high interdisciplinary antecedents is greater than the median assessment of all students. The results are displayed in Table VIII. We rejected the hypotheses in almost all cases, and therefore we assume that most interdisciplinary criteria are more important for students who have interdisciplinary antecedents.

We also compared the antecedents of students from different types of programs (i.e., the traditional program, doctoral school and doctoral colleges) using Kruskal-Wallis one way analysis of variance [50], which tests whether their criteria assessment originates from the same distribution. For each of the interdisciplinary antecedents, we tested the hypothesis for whether the medians of all doctoral programs are equal against the alternative that at least one of them is different.

TABLE VII
RESULTS OF THE WILCOXON TEST TO CHECK WHETHER THE
FULFILLMENT OF THE STUDENTS WITH HIGHER INTERDISCIPLINARY
Values, *Motivation* AND *Previous skills and knowledge* IS GREATER THAN
THE MEDIAN OF ALL STUDENTS.

Criteria	p-value		
(fulfillment)	Values	Motivation	Previous skills and knowledge
OVERALL INTERDISCIP.	**0.02**	**0.03**	0.05
WORK ENVIRONMENT	0.60	0.60	0.87
COURSES	**0.01**	**0.00**	**0.00**
METHODOLOGIES	0.62	0.66	0.81
COLLABORATION	0.06	**0.01**	**0.00**
CONTRIBUTION	0.11	0.13	**0.04**
CONCEPTUALIZATION	**0.00**	**0.00**	**0.00**
FUNDING	0.13	0.32	0.06
SUPERVISION	0.79	0.45	0.35
CO-SUPERVISION	**0.00**	**0.00**	**0.00**

TABLE VIII
RESULTS OF THE WILCOXON TEST TO CHECK WHETHER THE
IMPORTANCE OF THE STUDENTS WITH HIGHER INTERDISCIPLINARY
Values, *Motivation* AND *Previous skills and knowledge* IS GREATER THAN
THE MEDIAN OF ALL STUDENTS.

Criteria	p-value		
(importance)	Values	Motivation	Previous skills and knowledge
OVERALL INTERDISCIP.	**0.01**	**0.01**	**0.01**
WORK ENVIRONMENT	**0.01**	**0.02**	0.10
COURSES	**0.02**	**0.01**	**0.01**
METHODOLOGIES	**0.00**	**0.00**	**0.00**
COLLABORATION	**0.00**	**0.00**	**0.00**
CONTRIBUTION	**0.03**	**0.02**	**0.05**
CONCEPTUALIZATION	**0.00**	**0.01**	**0.02**
FUNDING	**0.00**	**0.00**	**0.00**
SUPERVISION	**0.00**	**0.01**	**0.01**
CO-SUPERVISION	**0.01**	**0.04**	**0.02**

The p-values of VALUES, MOTIVATION and PREVIOUS SKILLS AND KNOWLEDGE result in 0.38, 0.28 and 0.35. Since these p-values are higher than 0.05, the null hypothesis about equality of the medians cannot be rejected for each of the interdisciplinary antecedents. We could conclude that no statistical difference is observed in the interdisciplinary antecedents of students in these three kinds of programs.

D. Doctorate programs

We were also interested in the interdisciplinarity of doctoral students participating in different programs. For this reason, we grouped students according to the kind of doctoral program they are enrolled in, i.e., the traditional program, doctoral school, doctoral colleges. We used again the Kruskal-Wallis one way analysis of variance [50] in order to analyze the distribution of the assessment of these three groups of students on the fulfillment and the importance of OVERALL INTERDISCIPLINARITY. The tested null hypothesis assumed that the medians are equal for all the groups of students.

The resulting p-values are 0.37 for fulfillment and 0.50 for importance. Since the p-values are higher than 0.05, the null hypotheses cannot be rejected in both cases. This means there is no statistical difference between the fulfillment and the importance of OVERALL INTERDISCIPLINARITY across the programs.

VI. DISCUSSION

In this paper we propose a multiple-perspective assessment of the interdisciplinarity of doctoral education based on the 360-degree feedback methodology. With this methodology we integrate the views of different academic stakeholders in order to obtain not only a global assessment but also intermediate evaluations of each valuation criterion, doctoral program and group of stakeholders.

The results of this method provide information on the opinions of different academic stakeholders on interdisciplinary factors and processes within the context of an institution. This design allows for a comparison of stakeholders' opinions not only on the accomplishment of interdisciplinary criteria (fulfillment) but also on their relevance (importance). The utility of such a comparison lies in its informative potential. Achieving an alignment of around organizational objectives and stakeholders' expectations constitutes a significant step towards improving the performance and significance of the strategies in place as well as the development of new ones.

Concerning the context in which this study was conducted, this method provided evidence of a strong alignment of opinions of all stakeholder groups on the importance of training in interdisciplinary methodologies, as well as a discrepancy between professors and faculty directors on its fulfillment. The opinions of both stakeholder groups also differed in the importance that collaboration with experts in other disciplines has in the training of the doctoral students of the faculty. Discordances were also observed in the answers of faculty directors, who assessed interdisciplinary research as being quite important but consistently assessed the rest of the criteria as being of low importance. The analysis of such discrepancies between and within groups could serve as a base for developing a communication plan to gain both understanding and alignment of the different perspectives, which could eventually lead to a re-design of the assessment tool with new criteria.

The correlation analyses and statistical tests conducted on the criteria provide an indication of their relation to the interdisciplinarity of the research conducted by the doctoral students. The results of this analysis provide useful information as the criteria utilized in this study can be influenced with education and research policies. For instance, we found evidence that students who are co-supervised by experts in other disciplines conduct more interdisciplinary research. This is also the case for students with interdisciplinary antecedents. Therefore, if the faculty decides to promote interdisciplinary research, the results of this analysis could guide policy changes regarding doctoral supervision, undergraduate and graduate education, as well as doctoral admission.

The results also revealed the existence of undesired situations such as the missing correlations between the fulfillment and importance of adequate funding for interdisciplinary

research. This serves as a motivation for further analysis to explain the role that funding has on the production of interdisciplinary research at the given institution. The absence of significant differences between the interdisciplinarity of doctoral students of the different types of programs would also require the attention of the faculty to purposefully develop strategies to improve their relevance and value to interdisciplinary research.

While the proposed method allows for the analysis of an alignment of opinions, the planning of actions for improvement, and the identification of problematic issues, it has a limited explanatory and descriptive power and it does not measure interdiscipinarity per se. Such limitations have been addressed with the previous phases of this study (i.e., a qualitative analysis of interviews [7], and a measurement of interdisciplinarity based on a bibliometric method [6]). Nevertheless, this latest multi-perspective phase has provided additional insights that motivate further research with both qualitative and quantitative methods. In the evaluation of research interdisciplinarity it is argued that a conceptual framework with distinctive methodological tools is necessary given the complexity of the processes and factors that facilitate interdisciplinary research [31]. Therefore, the assessment of interdisciplinarity requires a multifaceted and multi-method approach. Schilling [51] referred to this complexity in the evaluation of interdisciplinary programs: "The hope for one single measure that will make our case is inappropriate for programs that embrace complexity and ambiguity as part of their core identity", which we confirm with our work. It is also important to note that the assessment should not be considered a single event, but a continuous cycle of planning and identifying goals, collecting and evaluating evidence, as well as implementing changes to planning based on that evidence [13], [52], [53].

ACKNOWLEDGMENTS

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