HowTo: Scientific Work in Interdisciplinary and Distributed Teams

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***Abstract*—Today's complex scientific problems often require interdisciplinary, team-oriented approaches: the expertise of researchers from different disciplines is needed to collaboratively reach a solution. Interdisciplinary teams yet face many challenges such as differences in research practice, terminology, communication, and in the usage of tools. In this paper, we therefore study concrete mechanisms and tools of two real-world scientific projects with the aim to examine their efficacy and influence on interdisciplinary teamwork. For our study, we draw upon Bronstein's model of interdisciplinary collaboration. We found that it is key to use suitable environments for communication and collaboration, especially when teams are geographically distributed. Plus, the willingness to share (domain) knowledge is not a given and requires strong common goals and incentives. Besides, structural barriers such as financial aspects can hinder interdisciplinary work, especially in applied, industry funded research. Furthermore, we observed a kind of cold-start problem in interdisciplinary collaboration, when there is no work history and when the disciplines are rather different, e.g. in terms of wording.**

Keywords—Interdisciplinary Collaboration, Science 2.0

I. Introduction

Many of today's real-world scientific projects require a team-oriented, distributed and interdisciplinary research approach. A prominent example of such a fruitful collaboration is the Large Hadron Collider in CERN, a project where researchers from different disciplines have created the largest and most powerful particle collider in the world. Another example is the Stanford Bio-X[1] interdisciplinary lab that bridges Life Sciences in the School of Medicine, Humanities and Sciences with Engineering and Physics to foster scientific collaborations to research on the human body with the aim to produce novel approaches to treating diseases. Such complex projects can't be tackled by only one discipline as the discipline would be confronted with challenges which can't be solved solely with its inherent paradigms [3]. Science has additionally become more and more global and nowadays, a wealth of Web 2.0 tools like for example Mendeley[2], Skype[3], Dropbox[4] exist that facilitate real-time communication and collaboration, which is especially helpful if teams are geographically distributed.

In this work, we reflect on our experiences we made with concrete mechanisms and tools for collaboration during two interdisciplinary, distributed scientific research projects. This reflection is based on Bronstein's model for interdisciplinary collaboration [4], which was originally targeted at social work professions. The model describes components of optimal collaboration as well as a number of influencing factors. Recent work [5] has suggested that alternating phases of collaboration and cooperation are crucial with respect to Bronstein's components to establish fruitful interdisciplinary collaboration. To the best of our knowledge, this extended Bronstein model has not been tested in a real-world setting.

By mapping our experiences to the extended Bronstein model, we validate in a bottom-up way, whether interdisciplinary and distributed scientific teamwork in the applied domains and included disciplines.

Our study is carried out in the context of two distributed, interdisciplinary research projects. The first project has been tackled in the context of the publicly funded European Union project Learning Layers[5]. Our aim was to invent a novel recommendation algorithm to recommend items to learners in an informal workplace learning situation. In the second project, we collaboratively designed and developed a prototypical knowledge management tool for the pharmaceutical industry in the frame of an industry funded, applied research project.

II. Model of Interdisciplinary Collaboration

Bronstein's model of interdisciplinary collaboration [4] provides a description of the components of optimal collaboration (see Figure 1). It describes five components of optimum interdisciplinary collaboration: (i) interdependence, (ii) newly created professional activities, (iii) flexibility, (iv) collective ownership of goals, and (v) reflection on process [4] (see also [5] for a detailed description of the model and its components). The model also describes four influencing factors: firstly, professional role, i.e., how a profession socializes its members, secondly, structural characteristics, i.e., an organization's desire to foster interdisciplinarity, thirdly, personal characteristics, i.e., how collaborators view others beyond their professional role and fourthly, history of collaboration that is defined by a person's past experiences with interdisciplinarity.

These factors are similar to the ones Brewer [1] named for interdisciplinary work: Firstly, different cultures and frames of reference. Secondly, different methods and operational objectives within and between the disciplines. Thirdly, institutional

[1]https://biox.stanford.edu
[2]http://www.mendeley.com
[3]http://www.skype.com
[4]http://www.dropbox.com
[5]http://learning-layers.eu

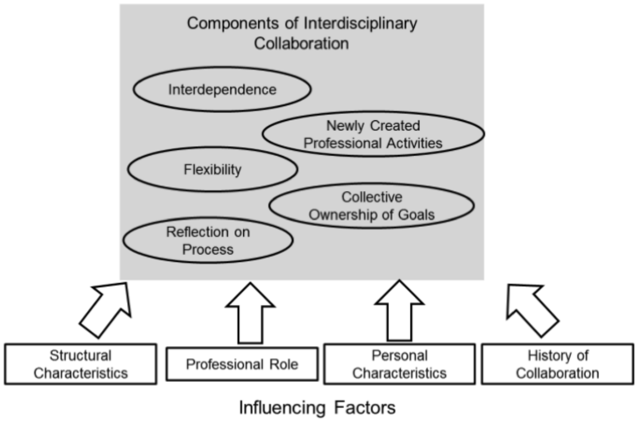

Fig. 1. The model for interdisciplinary collaboration as proposed by Bronstein [4]. The first part of the model describes the generic components of optimum interdisciplinary collaboration and the second part puts the model in context through an analysis of various influences on collaboration.

impediments related to incentives, funding, and priorities given disciplinary versus interdisciplinary work.

We used the model of Bronstein to categorize our experiences in distributed and interdisciplinary scientific teamwork, i.e. the applied mechanisms and tools. It is important to mention that the model does not differentiate between cooperation and collaboration. While cooperation describes the division of work into single sub-tasks being solved individually and merged in the end, collaboration describes the common solution of the work task by the involved partners [6] [7]. As argued in [5], efficient interdisciplinary work yet requires trust in each other's methods and competence. Therefore, the authors of [5] claim that it is necessary to split up after a profound collaborative phase and let each other do her/ his "job": i.e. cooperate based on complementary disciplines' skills. In the following, we describe both interdisciplinary projects, mechanisms and tools we used and relate them to Bronstein's extended model.

III. Developing an Item Recommender based on Cognitive Models

In the first project, a novel item recommender algorithm [8] has been developed over a time span of four months by a team of researchers in the context of the European Project Learning Layers[6]. Learning Layers is a large-scale research project co-funded by the European Commission's 7th Framework Programme consisting of a large number of European (research) institutions which cover all kinds of research disciplines. For example, the project requires expertise from the disciplines cognitive psychology, medicine, or computer science since it aims to technically support informal learning e.g. in the domain of construction and healthcare.

One of our roles in the Learning Layers project is to develop a service-based framework to facilitate informal learning at the workplace, the Social Semantic Server [9]. It provides all kinds of services to support the different ways of informal learning. One of these services represents recommendations to enable contextualized informal learning. Therefore, we have researched on novel recommendation algorithms to suggest items to learners.

In this project, our team consisted of six academics from two different disciplines and countries. Four computer scientists and two cognitive psychologists from two European universities collaborated on inventing the novel algorithm that is based on cognitive models. The cognitive psychologists contributed with expertise on cognitive models. The computer scientists were mainly responsible for the recommendation algorithm itself.

A. Mechanisms Used

First, we created a common virtual workplace for all distributed team members to tackle the collaborative work. We agreed upon a common cloud storage (i.e., Dropbox) to save preliminary results, exchange scripts, and relevant literature that was later required in the paper writing process. Besides, the collaborative paper writing process took place there as well. For the regular communication, we used both real-time communication tools (i.e., Skype) as well as e-mail.

We started the project with a series of virtual and face-to-face meetings, with the aim to discuss potential research collaborations and ideas. Each collaborator first presented her ideas, which resulted in a mutual discussion and reflection. After a defined time, in which everybody carried out further investigations in his field or expertise such as a literature search or preparation of code, all members of the research team met again with new proposals and ideas, as well as preliminary results. This iterative, multistage process consisting of collaborative and cooperative phases helped us derive a shared understanding of the research idea, its potential and limitations (*interdependence* component).

The ongoing process of exchanging knowledge and ideas enabled us to identify the research gap we wanted to tackle and to define our common project target, i.e., the implementation and evaluation of the novel item recommender algorithm. Besides, we agreed upon the common outcome of our project: a shared publication at a specific target venue. This corresponds to the *collective ownership of goals* component. We chose an interdisciplinary publication venue (i.e., the Web Science track at WWW'15) that best fit the needs of the entire team, which maps to *interdependence*, as well as *flexibility* since we had to find a common denominator, i.e., a venue that counts for both disciplines.

We then split up the work into two types of interdisciplinary tasks: (i) cooperative tasks tackled by a single discipline and (ii) collaborative tasks, i.e. tasks whose fulfilment require the team's complementary skills [5]. An example for (i) is the implementation of the algorithm, the preparation of the datasets for the evaluation and the preparation of the code so it can be uploaded to the open source repository Github[7]. Example for (ii) are shared discussions of results, of the structure of the paper, and of the target venue for the paper.

[6]http://learning-layers.eu

[7]We aimed for openness in the research process and therefore, the final version of the algorithm is available via the open source tag recommender framework TagRec [10]

We tackled the collaborative tasks by creating smaller focus teams. For example, a computer scientist regularly collaborated face-to-face with a cognitive psychologist to understand the main concepts of the underlying theory and their implications on the implementation of the algorithm. According to Bronstein's model, the cooperative tasks correspond to the *interdependence* component while the collaborative tasks relate to *flexibility*

Additionally, the whole team agreed on a weekly jour-fixe to collaboratively reflect on status and to carry out open discussions about the research topic and the preliminary results stored in the virtual workplace. This corresponds to *reflection on process*, *flexibility* and *collective ownership of goals* component.

In the next section, we report on the second project.

IV. Designing a knowledge management tool for the pharmaceutical industry

The pharmaceutical industry is challenged with the growing amounts of data and high data complexity, and therefore, the expertise from e.g. pharmaceutics, medicine, and computer science is required to better understand the data and thus to facilitate decision making. Pharmaceutical companies nowadays have a strong interest to leverage their data wealth as well as to better understand processes and products to increase efficiency and to avoid unnecessary investments.

To address this, we collaboratively designed and protoypically implemented a knowledge management system based on a specific modelling wiki [12]. This wiki enables to collaboratively construct knowledge about pharmaceutical products and processes and we extended it with functionality to analyze and visualize information extracted from a large corpus of open scientific publications that was crawled from the Web.

We developed the system with an interdisciplinary applied research team consisting of eight researchers: three computer scientists, four pharmaceutical engineers and one (cognitive) psychologist.

A. Mechanisms Used

We started the project with a series of meetings (virtual and face-to-face kick-off). Each collaborator presented her domain and viewpoint on the interdisciplinary teamwork, resulting in a mutual offer from each discipline. Afterwards, the collaborators reflected and discussed about the offers via instant messaging (i.e., Skype) for direct communication, informal discourse and urgent issues and/or e-mail, when e.g. information had to be distributed to all team members at once. Then, we met again with new proposals and ideas. This helped us deriving a shared understanding of the project, its potential and limitations and finally to develop a common project target and outcome (*collective ownership of project goals* and *interdependence*).

Similar to the first project, we split up the work into single discipline, cooperative tasks, as well as multi-discipline, collaborative tasks. In the cooperative phase, e.g. the group of computer scientists first implemented data mining and visual analytics tools to enable the analysis of pharmaceutical (scientific) publications and research data. Then, the algorithms were tailored towards the pharmaceutical domain based on the feedback pharmaceutical engineers gave to the results the algorithms produced. In the collaborative phase, a psychologist worked together with a pharmaceutical engineer on transforming knowledge about pharmaceutical processes into domain and process models. The psychologist, a trained knowledge engineer, contributed knowledge about modelling, process construction and on how to design a wiki for meaningful collaborative knowledge construction. The pharmaceutical engineer as domain expert provided input about the domain to be modelled. In addition, a chosen group of pharmaceutical engineers constantly provided feedback and validated the results. As described earlier, the cooperative tasks correspond to the *interdependence* component, and the collaborative tasks to *flexibility*. After the domain core was collaboratively modelled and the pharmaceutical engineer was familiar with the modelling task, in later stages of the project, she carried on modelling by herself and regularly discussed the results with the psychologist in virtual meetings. This training of the pharmaceutical engineer in modelling of domains resulted in and the creation of *newly created professional activities*.

In this project, the final wiki-based knowledge management system and - thus the outcome of the project - served as our common virtual workplace. The data mining/visual analytics tools were instantly integrated into the system so that all team members could access the latest results, work directly with the tools and provide feedback (i.e. support and speed-up in cooperative phases). The collaborative domain modelling task was also done directly in the system. All other communication and/or information sharing needs could be met either synchronously (Skype) or asynchronously via e-mail.

Regular (virtual or face-to-face) jour-fixe meetings helped us collaboratively reflect on status and progress as well as to manage expectations (*reflection on process*, *flexibility* and *collective ownership of goals*). To strengthen the long-term effects of the project, we started an interdisciplinary training, more specifically, a PhD thesis related to the project has been kicked-off and it will be supervised by partners from all disciplines (*newly created professional activities*).

V. Discussion and Findings

At the beginning of both projects, it was challenging to tackle the work in the collaborative tasks since they require a lot of communication, ideally face-to-face time but also virtual meeting time to sit and work together. The cooperative tasks require mutual trust in each discipline's competencies as one discipline positively depends on the other's skills. We found that alternating phases of cooperation and collaboration are indeed crucial as trying to solve the problem together would take too much time and it would not lead to trust in the disciplinary abilities [5]. Naturally, also willingness to learn from each other's discipline is beneficial (*personal characteristics*). We also found that in our case *interdependence* is mainly important in cooperative phases and the component *collective ownership of goals* more in collaborative phases. The components *reflection on the process* and *flexibility* are on the contrary essential for both phases, collaborative as well as cooperative.

We encountered that the willingness to share (personal) knowledge across disciplines represents a crucial professional challenge: In the pharmaceutical industry, it is not always common to make knowledge explicit because knowledge means market advantage (*structural characteristics*). This has not been the case in the publicly funded research project Learning Layers. Especially in respect to the principles of Science 2.0/Open Science, this difference is fundamental and it has a manifold of implications, if we consider for instance reproducibility as one crucial aspect of science[8].

We realized that finding a common environment for collaboration can be challenging since researchers from different disciplines may have their own practices and preferences (*professional role* and *personal characteristics*). We found that using the right tool for communication is key: e-mail exchange can complicate mutual understanding, and therefore, real-time communication was preferable in many situations as it enabled us to quickly resolve misunderstandings.

From our experiences, interdisciplinary projects may face problems with setting priorities due to the unknown outcome at the beginning (*structural characteristics*). For the first project, i.e. inventing a novel recommender algorithm, priority setting and appreciation was less of a problem as we very soon agreed upon creating a shared publication together. This created an incentive for all team members to stick to the common goal as the outcome was rather predictable and beneficial for everybody. Plus, parts of the team have worked together over one year already (*history of collaboration*). As described in [13], prior experience with a collaborator reduce the barriers of interdisciplinarity. For the more industry driven second project, setting priorities was interestingly more of an issue, since at that time, the project was not the most pressing issue for the company, as interdisciplinary project often are due to financial or structural barriers [2].

Besides, the second project lacked the strong common goal at the beginning with clear incentives for all involved parties. There was no former history of collaboration at project start and the involved disciplines were very different, e.g. in terms of wording. To tackle this kind of cold-start situation, we first had to build up shared understanding and mutual trust in each discipline's abilities, as well as a work history. This has been achieved through alternate phases of collaboration and cooperation, through meetings and discussions. Only afterwards, we were able to define a strong common goal that was beneficial for all. Specifically, we agreed to present the outcome and the benefits of our interdisciplinary collaboration to a larger audience by organizing the joint SmartPharma workshop at the i-Know 2012 conference, a scientific conference that has a strong industry track (*collective ownership of goals*).

VI. Conclusions

In conclusion, we found first evidence that Bronstein's model of interdisciplinary collaboration applies to our interdisciplinary scientific work, and that alternating phases of collaboration and cooperation positively influence interdisciplinary work. Furthermore, we observed a kind of cold-start problem in interdisciplinary collaboration, when there is no work history and when the disciplines are rather different, e.g. in terms of wording. In that case, we found that the communication costs are high especially at the beginning of a project. For future work, we will investigate whether and how these costs can be minimized. We would also like to investigate the impact of each of the components and influencing factors on the actual project success. Finally, we will investigate which Science 2.0 tools and methods are best suited to support collaboration and cooperation and whether such tools could also help diminish negative effects of certain influencing factors such as structural characteristics.

[8]http://www.nature.com/nature/focus/reproducibility

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