



# Transfer of knowledge through international scientific mobility: Introduction of a network-based bibliometric approach to study different knowledge types

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## ABSTRACT

Although international mobility is associated with various positive outcomes, the process of knowledge transfer resulting from working abroad has not yet been sufficiently investigated. The main reason why the relationship between international mobility and knowledge transfer is still underresearched is that there are not yet reliable methods to identify knowledge transfer. The current study aims to close this research gap by introducing a network-based approach that is capable of indicating knowledge flows. Assuming that coauthorship constitutes one instance through which knowledge transfer can take place, the approach relies on coauthorship networks. In the first approach to be presented, the transfer of published knowledge is operationalized as the use of rarely cited publications. In the second approach, the transfer of methodological know-how is operationalized as the occurrence of lexical terms in abstracts of publications. The study focuses on German scientists who were internationally mobile and acted as knowledge transmitters between the country of mobility and Germany. The results show that the network-based approach is well suited to identifying the sources of knowledge, knowledge transmitters, and the recipients of knowledge. Moreover, the findings suggest that knowledge transfer processes are field specific.

## 1. INTRODUCTION

International mobility describes the movement of scientists between research organizations located in different countries of the world. International mobility may become a necessity when the knowledge desired is located in another country and requires physical mobility across state borders. Whereas some knowledge types can be transmitted through scientific publications or the attendance of conferences, other types of knowledge are place specific and demand international mobility. The experience of being internationally mobile is associated with many positive effects on the career trajectories of scientists (Jonkers & Cruz-Castro, 2013; Kyvik, Karseth, Remme, & Blume, 1999; Leahey, Beckman, & Stanko, 2017). Previous studies have focused mostly on the relationship between mobility and collaboration and the effect on productivity and impact in science (Aksnes, Rorstad, Piro, & Sivertsen, 2013; Gibson & McKenzie, 2014; Halevi, Moed, & Bar-Ilan, 2016; Markova, Shmatko, & Katchanov, 2016; Sandström, 2009; Sugimoto, Robinson-Garcia, et al., 2017). Even though the number of

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studies on international mobility of scientists has increased in the last few years, the effect of international mobility on the acquisition and transfer of knowledge has not yet been sufficiently investigated. This is mainly because there are no well-established methods to trace knowledge flows. To identify knowledge transfer as a process inherent to international mobility three issues must first be addressed: the identification of the actors involved, the international mobility of a possible knowledge transmitter, and finally the flow of knowledge from a source of knowledge to the recipient of knowledge. The use of publications to trace scientists' mobility was introduced by Laudel (2003), who studied the affiliations of scientists' publications throughout their careers. A comprehensive taxonomy for studying international scientific mobility using bibliometric data was provided by Robinson-Garcia, Sugimoto, et al. (2019).

While previous research has made it possible to identify actors by the use of Scopus author ID (Moed & Halevi, 2014) and to identify the international mobility of scientists by the change of their affiliations (Aman 2018b; Conchi & Michels, 2014), the identification of knowledge transfer remains a challenging issue. To date, we have no reliable methods to objectively indicate knowledge transfer. Existing approaches are mostly qualitative in nature, including interviews and questionnaires, which are time consuming and costly and require pre-existing knowledge of the topic (Chen & Hicks, 2004). Interest in understanding the mechanisms facilitating the transfer of scientific knowledge has been present in the sociology of science since Merton (1968). Seminal qualitative studies of knowledge transfer can be traced back to Collins (1974, 2001), who empirically described the knowledge transfer process, concluding that personal contacts between scientists are essential to transfer tacit knowledge.

Issues related to knowledge transfer have captured the attention of scholars in various disciplines, such as health science, educational research, social sciences, and natural sciences. Because knowledge cannot be directly observed, one has to rely on proxy measures. Previous studies have used citation linkages between articles that assume a flow of knowledge from the cited to the citing article (Zhuge, 2006). The operationalization of knowledge flows by citation linkages provided results on the interrelation of disciplines (van Leeuwen & Tijssen, 2000) and the identification of scientific fields that act as knowledge exporters or importers (Yan, Ding, Cronin, & Leydesdorff, 2013). Based on publication and citation data, Hassan and Haddawy (2013) mapped knowledge flows among countries in the field of energy. However, the reliability of citation flows as a measure of knowledge transfer has not yet been validated.

Further studies dealt with the knowledge recombination of coworking scientists rather than knowledge transfer, showing that knowledge from distant places is often more innovative and creative than local knowledge (Fleming, 2001; Franzoni, Scellato, & Stephan, 2014). On the basis of survey data, Franzoni, Scellato, and Stephan (2018) found that internationally mobile workers who own highly fragmented and specialized competencies show better performance when the relevant knowledge is geographically concentrated ("recombined"), as opposed to when it is widespread.

Thus, there are qualitative studies, surveys, or bibliometric studies that so far have used only citations to model knowledge flows. In contrast, this study aims to present further approaches to study the transfer of knowledge. To this end, I work with the distinction of three knowledge types as proposed by Gläser (2006), stating that scientists are confronted in their daily business with published knowledge, informally communicated knowledge, and tacit knowledge.

The first approach to be presented is able to detect the transfer of published knowledge by studying the flow of references among scientists. In contrast, the second approach draws on lexical terms that aim to operationalize the transfer of methodological know-how. This knowledge type is associated with informally communicated and tacit knowledge (Gläser, 2006),

which is hard to verbalize and is rooted in experiences and actions. In both the approaches, internationally mobile scientists act as knowledge transmitters between the sources of knowledge and the recipients of knowledge.

This paper is a follow-up study of a longer research project dealing with the development of methods to detect knowledge transfer resulting from international mobility. In a previous study of the project, I examined the reliability of the Scopus author ID to identify authors and tested whether it suffices to track the international mobility of scientists by comparing the mobility data of scientists from Scopus publications with CV-based data on residence countries (Aman, 2018b). In a subsequent study, I approximated knowledge transfer using the cosine similarity (Aman, 2018a). The main idea was that whenever internationally mobile scientists interact with scientists abroad they become similar to one another in their choice of references cited and lexical terms used in abstracts. Whereas the study on similarity did not pay attention to the knowledge types transferred, the present study tries to test different approaches for different types of knowledge.

In the following sections, I provide a theoretical background on the relationship between international mobility and knowledge transfer, and carve out the bibliometric data used to operationalize knowledge transfer. The remainder of the paper describes the database used and explains the interpretation of the network-based representation of knowledge transfer. After presenting the results of the approach, I discuss the main findings and limitations of the study. I conclude by pointing out the relevance of this work and provide an outlook for future studies.

## 2. THEORETICAL BACKGROUND

The essential theoretical foundations of scientific knowledge, knowledge production, and knowledge transfer were established in the sociology of science without the existence of a standardized definition of scientific knowledge. It is thus in the very nature of knowledge that any definition of knowledge would be incomplete and inadequate. By *scientific knowledge* I refer to knowledge claims produced by research groups in the process of science that are communicated verbally or in writing. Scientists seek to produce knowledge and disseminate their scientific achievements among the scientific community (Merton, 1957). They contribute to the collective body of knowledge by publishing and referencing knowledge claims (Gläser & Laudel, 2001). These knowledge claims are encoded in publications, enabling their diffusion among the scientific community. However, a large part of the knowledge produced remains tacit and cannot be transferred by publications alone. Thus, to identify the transfer of some types of knowledge requires observation of the knowledge bearers and interaction with them. This is where international mobility and copresence become an important factor in the acquisition and transfer of knowledge. Knowledge transfer can be intentional, but also unintended and discretionary, such as during interactions with peers, which enable accidental knowledge transfer. However, scientific knowledge is specialized and will only be acquired if the recipient of the transferred knowledge has the ability to interpret the knowledge. Further, knowledge transfer between scientists can also fail because information is withheld, not understood, or rejected as useless.

For the purpose of this study, by *knowledge transfer* I refer to the passing on of scientific knowledge from a source of knowledge to a recipient of knowledge. As a result of the knowledge transfer the source and the recipient share knowledge about the same object of study. Moreover, an internationally mobile scientist acts as an intermediary, transmitting the knowledge from the source to the recipient.

There have been many attempts to develop classifications of knowledge and explanations of how it is transferred. One of the earliest classifications of knowledge is that of Russell (1911), which distinguished between knowledge by acquaintance and knowledge by description. In a scientific context, knowledge by acquaintance would refer to knowledge that is obtained through interaction between a scientist and the object that the scientist is observing. In contrast, knowledge by description can be transferred by a scientist or learned autonomously from a publication. Another basic distinction of knowledge types goes back to Polanyi (1966), who distinguished explicit knowledge from tacit knowledge. The former is mostly published and easily circulated, whereas the latter is embedded in the experiences and skills of the individual and only revealed in action. Tacit knowledge is necessary in addressing hard-to-tackle or research-front issues, which are usually accessible to only a few specialized individuals or research groups (Polanyi, 1966).

Gläser (2006, pp. 108–113) established a suitable distinction of three knowledge types: *published knowledge* that is available to the scientific community, *informally communicated knowledge* that is communicated on demand between scientists, and *tacit knowledge* that refers to the highly individualized knowledge that can hardly be expressed verbally and therefore requires face-to-face communication and observation.

Following Gläser's (2006) distinction and theory about the way knowledge is acquired and transferred, published knowledge can be independently acquired without personal contact or the need for local proximity. However, international mobility enables coworking, whereby relevant publications can be recommended by colleagues.

Informally communicated knowledge refers to methodological know-how and knowledge about practical problems in daily work that are not manifested in publications but exist in scientists' minds (Gläser, 2006, p. 112). International mobility as well as the use of information and communications technology (ICT) enable the transfer of informally communicated knowledge. The transfer of informally communicated knowledge during an international stay could be the advice to apply the best practice concerning an issue. Finally, it is only copresence that enables the transfer of tacit knowledge. Thus, if the knowledge to be transferred is of a tacit nature and bound to specific facilities or persons located abroad, international mobility becomes a necessity. The transfer of tacit knowledge could be inherent to the demonstration of laboratory methods or unveiling an innovative step in an experiment that has not previously been described but becomes crucial for smooth operation (Gläser, 2006).

Published studies on true observations of knowledge transfer are rare. So far, social science studies have analyzed the transfer of tacit knowledge and neglected the transfer of other types of knowledge. Pivotal studies of tacit knowledge and the role that international mobility plays in adapting the place-specific knowledge date back to Collins (1974, 2001). Collins (1974) described a situation where the TEA laser could be constructed by those scientists who had the chance to see the original setup and to interact with its constructors, whereas scientists who studied only diagrams were not able to replicate the laser.

In a further study, Collins (2001) demonstrated that the unavailability of the tacit knowledge required to measure the quality factor of sapphires forbade the West to replicate what Russian scientists had achieved 20 years earlier. However, the international mobility of the knowledge bearer and the observation of his skills and the interaction with the research group enabled the disclosure of the trick of the trade. Evidently, the physical proximity of scientists facilitates the acquisition of skills and tacit knowledge, enabling the correct translation of contextualized knowledge into the correct application of knowledge.

To conclude, a large part of knowledge is uncodified and resides tacitly in the minds of individuals. It cannot be acquired except by working in proximity with the owners of the knowledge (Franzoni et al., 2018). Tacit knowledge resists diffusion and requires knowledge carriers to transfer knowledge over geographical distances (Trippel, 2013; Williams & Baláz, 2008). Moreover, international mobility enables the dissemination of knowledge across the globe and encourages new combinations of knowledge (Laudel, 2003). Whenever scientists interact, knowledge is not only transferred, but also expanded or modified, making knowledge transfer a key factor in knowledge production.

### 3. DATA AND METHODS

#### 3.1. Database and Operationalization

This section describes the data used to develop the two distinct approaches and the coauthorship relation on which both approaches rely. At its core, the operationalization of the two different types of knowledge is explained.

The data were retrieved from the Scopus database (Elsevier). These data are licensed and integrated in an in-house database version at the Competence Centre for Bibliometrics<sup>1</sup>. The scientists under study were identified by their author ID in Scopus. The author ID combines all publications of an author under a single ID to handle common first and last names (Moed et al., 2013). A number of studies report that Scopus author ID is a powerful algorithm in terms of recall and precision (Aman, 2018b; Conchi & Michels, 2014; Moed, Aisati, & Plume, 2013). Mobility was identified by using the address information recorded in publication metadata. Internationally mobile scientists were identified as those whose affiliation changed from one country to another. The country relates to the geographic location of the institute reported by the authors on their publications.

Another data source was of qualitative nature. An internationally mobile scientist from Germany was interviewed in 2009, reporting how he intended to go abroad to acquire knowledge about a specific biological method<sup>2</sup>. The interview data were substantiated by bibliometric data and used as a proof of concept.

The publications of authors enable the establishing of relations among different attributes (e.g., references, coauthors, or lexical terms). In both of the approaches to be presented, I focus on coauthorship relations. Coauthored publications are the best proxy of scientific collaboration (Katz & Martin, 1997) and help to understand how scientists are interconnected. Joint research publications reflect successful scientific collaboration and are likely to be indicators of knowledge transfer between scientists. Whenever two or more authors are listed as coauthors on the same publication, it is likely that they have collaborated and exchanged knowledge (Laudel, 2002). Coauthorship is thus an indicator of collaboration, which in turn enables the exchange of different knowledge types (e.g., tacit knowledge that is not yet codified in publications).

The influence of a scientist's work upon that of another can be detected by the articles that a knowledge recipient publishes. Indications of such influences are, for instance, citation references in articles or the use of lexical term combinations. Informing colleagues about relevant literature is one specific form of knowledge transfer and is operationalized in this study as the passing on of knowledge about the existence of a publication. The absorption of a reference into another scientist's work is analyzed in this study irrespective of the multidimensional

<sup>1</sup> Competence Centre for Bibliometrics: <http://www.forschungsinfo.de/Bibliometrie/en/index.php?id=home>.

<sup>2</sup> The interview was conducted by Grit Laudel for a previous study.

reasons to cite (e.g., Bornmann & Daniel, 2008). Citing a specific work may also be influenced by social factors: For example, authors primarily cite works by those with whom they are acquainted (White, 2004).

Sharing knowledge with colleagues about a newly established method is another form of knowledge transfer and is operationalized in this study as the passing on of methodological know-how. To represent the transfer of methodological know-how, specific lexical terms from the abstracts of publications were used.

### 3.2. Approach to Identify the Transfer of Published Knowledge

As a first step, I identified all the scientists in Scopus who had published at least one publication with a German affiliation between 2012 and 2017. Publications were limited to journal articles, reviews, and conference proceedings as these publication types typically include new knowledge claims. There were in total 607,415 author IDs with at least one German publication in this 6-year period. To exclude situations in which two or more authors may have been merged into one Scopus author ID (mostly due to common names) and to guarantee that the scientists publish actively, the publication count was limited to three to 200 publications between 2012 and 2017. The focus of the study was German scientists (i.e., authors who published the majority of their publications between 2012 and 2017 in Germany). This group of scientists is referred to from here on as *German scientists*, irrespective of their nationality. Overall, there were 212,925 German scientists. Among these German scientists, only those who were internationally mobile are of interest. International mobility was operationalized by having first published in Germany, and then in a country other than Germany, and then again in Germany—all within 2012 and 2017. Figure 1 provides an overview of the three nonoverlapping phases of German scientists' careers in the period 2012 to 2017. In the pre-mobility phase and the post-mobility phase, German scientists must have published exclusively from German institutions. The mobility phase 2014 to 2015 is characterized by at least one publication affiliated to a non-German institution.

The longer the period before and after mobility, in which German scientists exclusively publish with German affiliations, the stricter the constraint, because scientists can intend to become internationally mobile again. In addition, the duration of stays abroad can vary widely among disciplines. In the example to be presented in the second approach (section 3.3), the scientist decided to split his 2-year scholarship into an experimental part of 15 months in the USA and a computational part of 9 months in France. Because the bibliometric data only approximate the countries of residence, a mobility phase of 1 or 3 years can lead to two publications in 2 consecutive years (Aman, 2018b).

Scopus' All Science Journal Classification (ASJC) codes were used to determine the descriptors (scientific disciplines) of the authors' publications. Because authors' publications can belong to multiple descriptors, I identified the dominant descriptor (i.e., the descriptor that



**Figure 1.** Illustration of the three nonoverlapping phases in the careers of German scientists under study.

**Table 1.** Overview of the 10 most common ASJC dominant descriptors of German scientists who were internationally mobile between 2014 and 2015 in relation to all German scientists publishing between 2012 and 2017. The last column shows the average number of coauthors of mobile scientists.

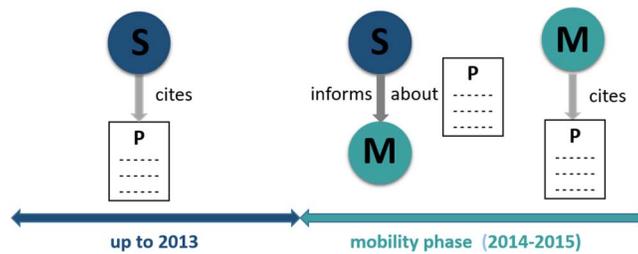
ASJC dominant descriptor	No. of German scientists in 2012–2017	No. of mobile scientists	Share (%)	Average no. of coauthors of mobile scientists
Medicine	35,108	826	2.35	146
Physics and Astronomy	17,631	461	2.61	116
Biochemistry, Genetics and Molecular Biology	15,547	368	2.37	156
Chemistry	16,964	248	1.46	80
Agricultural and Biological Sciences	14,364	211	1.47	99
Materials Science	12,504	194	1.55	86
Computer Science	11,727	192	1.64	40
Engineering	10,388	181	1.74	60
Neuroscience	6,311	144	2.28	146
Earth and Planetary Sciences	5,168	112	2.17	90
Total	145,712	<b>2,937</b>	2.02	

was assigned to the majority of an author’s publications). Table 1 lists an overview of those 10 descriptors with the highest number of internationally mobile scientists publishing between 2012 and 2017. The first column shows the dominant descriptor in Scopus and is followed by the total number of German scientists publishing between 2012 and 2017 according to descriptor. The third and fourth columns provide information on the number and share of scientists who were internationally mobile between 2014 and 2015. The last column lists the average number of coauthors of internationally mobile authors.

The majority of German scientists who went abroad, in terms of numbers, belonged to Medicine, followed by Physics and Astronomy. The highest share of internationally mobile scientists can be found in Physics and Astronomy, followed by Biochemistry. The lowest share of internationally mobile scientists belonged to Chemistry and Agricultural and Biological Sciences.

Coauthors were restricted to those who had at least one joint publication with a German scientist in the data set and not more than 200 publications between 2012 and 2017 to exclude merged identities. The publications of coauthors were also restricted to journal articles, reviews and conference proceedings. In a following step, all references that were cited by the mobile scientists were identified, along with the first year in which the reference was cited. From there I determined the publication year of coauthors who cited the same references as the German scientists for the first time.

Figure 2 illustrates the transfer of published knowledge from the coauthor abroad to the internationally mobile scientist. The node S represents the source of knowledge who is a future coauthor of the mobile scientist M. S cites a publication P up to 2013, thus before an interaction appeared between S and M or a coauthored paper was published. It is assumed in the model that during mobility, S informs M about the publication. S and M are connected by



**Figure 2.** Illustration of the transfer of published knowledge. S represents the source of knowledge, who is the future coauthor of the internationally mobile scientist M. S cites publication P before the first coauthored article of S and M is published. During mobility knowledge about the publication is shared and the mobile scientist cites P in an article of his or her own.

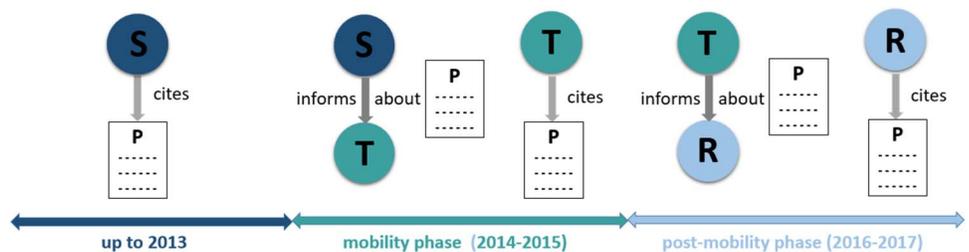
coauthorship that is not necessarily related to the cited publication P. While abroad M cites the same publication P for the first time in a work of his or her own.

The timeline stresses that the references of interest must have been used by the coauthor (S) earlier than by the German scientist (M). Thus we can conclude that these coauthors act as knowledge sources and point to publications that German scientists later adopt into their work.

To trace the passing on of publications, the references were limited to those that were not cited more than 100 times (i.e., there were fewer than 101 publications in Scopus in the years 1996 to 2017 that cited the reference under study). Because rarely cited articles are less visible than highly cited ones (Russel & Rousseau, 2009), the probability is low that scientists take note of these references. In contrast, scientists are more likely to have become aware of the rarely cited references by studying the publications of their coauthors or following their recommendation to read the rarely cited paper. If multiple coauthors of the mobile scientist can act as knowledge sources up to 2013, I selected the one who cited the reference first.

A further condition of the approach is that knowledge acquisition abroad is sustainable in the sense that the knowledge acquired by the mobile scientist is passed on to another scientist upon return in Germany (recipient of the knowledge). Figure 3 illustrates the complete knowledge transfer from source S to the mobile scientist T and then to the recipient R. Because the mobile scientist in the previous Figure 2 has the function of a transmitter between the source abroad and the recipient back in Germany, the nodes M were renamed to T.

To model the knowledge transfer from the mobile scientist to a recipient of the post-mobility phase, the knowledge about the same publication has to be passed on to coauthors who have not yet cited the publication in their own work. Thus, the recipients of the knowledge are newly



**Figure 3.** Illustration of the knowledge transfer process from source of knowledge S to the transmitter T who is the mobile scientist. The recipient R of the knowledge is a coauthor of T and receives the knowledge of the publication P upon return of T to Germany.

established coauthors. Finally, there were 989 authors and 5,829 distinct references which allowed the tracing of knowledge transfer from a source of knowledge (coauthor of German scientist prior to mobility) to a transmitter of knowledge (German scientist being mobile) to a recipient (coauthor of German scientist after mobility). The knowledge transfer is directed so that the earliest year in which an author can act as a source is 1996, as a transmitter during mobility between 2014 and 2015 and as a recipient between 2016 and 2017.

A control group consisting of German scientists who were not internationally mobile between 2014 and 2015 was created for comparison. The delineation of the control group equals that for the mobile scientists except for the fact that these German scientists had not been abroad but published with an exclusively German affiliation in 2014 and 2015. However, they could have international coauthors in all of the three phases. The number of nonmobile scientists is quite high, so that I took a comparably large sample of 3,000 scientists to detect knowledge transmitters. This control group shows how far international mobility is dispensable in terms of the transfer of published knowledge.

### 3.3. Approach to Identify the Transfer of Methodological Know-how

In the following, I will illustrate that the use of lexical terms can be used for the operationalization of the transfer of methodological know-how. This explorative approach used interview data as a point of departure<sup>3</sup>. In that way the interview data underpin the bibliometric findings and serve as a validation. The original interview data provide insight into the scientist's ambition to go abroad in order to acquire knowledge about a newly established method in molecular genetics:

And there a protein family was described, that is called X. In 2000 or 2001, I think it was described for the first time. And I knew [person A] from my diploma thesis, who also stumbled upon this protein. In fact, it was the very first X-protein ever to be described in [object Y] and I knew that she had the right methods to understand these proteins. The hypothesis was that these X-proteins are the factors that make these base exchanges and other things in the RNA metabolism of [object Y]. And I wanted to find out if that was true. Yes and that is why I took this step to go to this lab and to work the other half in [person B]'s lab in France. He had described the family bioinformatically, had bioinformatic expertise to analyse this family. And therefore this split stay, so the experimental part in [US state] and then this bioinformatic part in [city in France].<sup>4</sup>

The scientist went to a lab where the method for understanding a specific protein was developed. The transfer of knowledge about a method is associated with the transfer of

<sup>3</sup> The interviews were translated from German to English, with names, objects, and place being anonymized. The concrete amino acid sequence motif cannot be published for data protection reasons.

<sup>4</sup> Original interview data: "Und da wurde gerade eine Protein-Familie beschrieben, die heißt eben X. Im Jahr 2000 oder 2001 war das glaube ich zum ersten mal beschrieben worden. Und ich kannte halt [Person A] von meiner Diplomarbeit die auch über eines von diesen Proteinen gestolpert war. Genau genommen war es das allererste X-Protein das überhaupt in [Objekt Y] beschrieben wurde und ich wusste, dass sie die richtigen Methoden hat, um diese Proteine zu verstehen. Die Hypothese war diese X-Proteine sind die Faktoren, die diese Basenaustausche machen und noch andere Dinge im RNA-Metabolismus von [Objekt Y]. Und ich wollte herausfinden, ob das stimmt. Ja und deshalb halt dieser Schritt in dieses Labor zu gehen und aber die andere Hälfte im Labor von [Person B] zu arbeiten in Frankreich. Der hatte die Familie bioinformatisch beschrieben, hatte bioinformatische Expertise, um diese Familie zu analysieren. Und deshalb halt dieser geteilte Aufenthalt, also der experimentelle Teil eher in [US-Staat] und dann dieser bioinformatische Teil in [Stadt in Frankreich]."

informally communicated and tacit knowledge (Gläser, 2006). In this example, the tacit knowledge exists locally as methodological know-how, which is difficult to transfer, as it is deeply rooted in the way an individual performs a method. Experimental methods for studying proteins include, for instance, the extraction of the RNA, labeling, and analysis using microarrays. Tacit knowledge can be acquired only through direct instruction or via observation and imitation. Informally communicated knowledge, which is also inherent to the acquisition of methodological skills, is verbal in nature and includes things such as rules of thumb or tricks of the trade.

Based on the interview data, I developed a bibliometric data set containing all authors who published on the newly established molecular biological method for the study of specific proteins. The authors in the network were identified via the following method: The abstracts of their publications had to contain two lexical terms that were specific enough to identify the molecular biological method and the protein. A thorough look at the results shows that the delineation leads unambiguously to scientists working on that topic. The publications were limited to the years 2003 to 2008. According to Scopus data the first article in which the method was applied was published in 2003, whereas 2008 represents the year in which the research group in France acquired the knowledge of the method.

#### **3.4. Network-based Representation of Knowledge Flows**

The findings of both approaches are expressed as network-based representations. The graphs facilitate the understanding of the network structure and include detailed information about coauthorship patterns and the passing on of publications and methodological know-how respectively. This is achieved by the specific layout of the network and the use of node and edge colors to distinguish actors and years.

In both approaches, nodes represent the authors and coauthors who used a reference or lexical terms. A node is connected to another node only if the authors represented by these nodes have a coauthored publication. Thus, if two nodes have at least one shared publication, an edge is established. The authorship is unweighted: Neither the weight of the edge nor the size of the node is affected by the number of shared articles.

In the first approach, nodes represent authors using a reference and the node size represents the number of publications in which the reference was used. From a theoretical point of view, the larger the node, the higher the probability for knowledge transfer. The colors of the nodes represent the years in which the reference of interest was used in a publication for the first time. The darker the node color, the earlier the use of the reference. The edges are directed, presenting the flow of knowledge from one node to another. The color of the edges informs about the first coauthored publication of two nodes irrespective of time or theme. The darker the edge color the earlier the year in which the first coauthored publication was published.

In the second approach, the nodes correspond to authors using the method under study in their publications. As in the first approach, two authors are connected if they have coauthored in the past on any topic and not necessarily the topic depicted in the graph. The edges represent the knowledge transfer from one node to another and the arrows of the edges support the idea that the knowledge transfer is directed. The coauthorship network of the second approach represents the diffusion of methodological know-how from one research group to another.

The network diagrams are produced with Gephi 0.9.2 using the Force Atlas algorithm, a variant of the Fruchterman–Reingold force-directed algorithm (Bastian, Heymann, & Jacomy, 2009). In the first approach the nodes are arranged on a time line to better explain the passing

on of publications. In the second approach the nodes are positioned on the basis of repulsion and attraction, so that authors copublishing a lot are pulled together, whereas authors not copublishing are pushed to the outskirts.

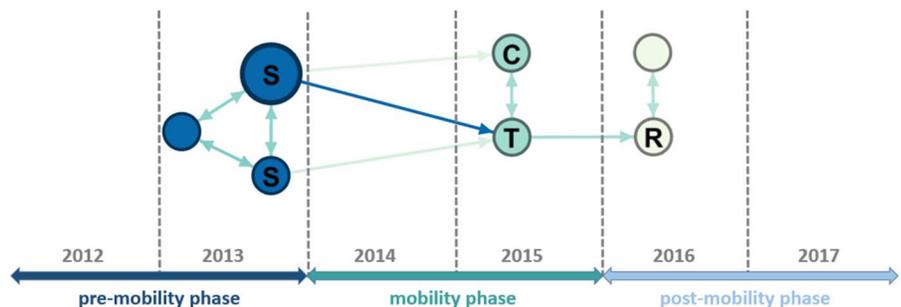
#### 4. RESULTS

##### 4.1. Approach to Identify the Transfer of Published Knowledge

In the following section, the results of the two approaches described in the previous section are presented. The first approach deals with the network-based visualization of authors using a specific reference. The analysis of the findings entails the detection of the source of knowledge (S), the transmitter of knowledge (T), and the recipient of knowledge (R). Moreover, the networks provide information about the flow of knowledge and the coauthorship relations.

Figure 4 presents a network of scientists citing a book (Ruzmaikin, 1988). The network consists of nodes representing authors using the reference and edges connecting these authors by coauthorship irrespective of time or theme. Visual inspection of the network in Figure 4 shows that there are two coauthors from the mobility phase who act as sources of knowledge (S). We can derive from the network that three coauthors cited the publication under study for the first time in 2013 before the German mobile scientist T had interacted with them. The mobile scientist T used the reference in a publication of his or her own for the first time in 2015. Upon return to Germany, the internationally mobile scientist passed the knowledge about the publication on to a newly established coauthor (R) who cites the publication in 2016 for the first time.

Node C in Figure 4 represents a coauthor of the knowledge transmitter. One could assume that the knowledge was passed on from the source of knowledge (S) to the coauthor (C) and was then adapted by the knowledge transmitter (T). However, the coauthorship between node S and node C came into being later than that between node S and node T, as indicated by the edge color. Therefore, it is more likely that the knowledge was passed on from node S to node T, suggesting that the internationally mobile scientist acts as a knowledge transmitter while being abroad. Table 2 provides a comparison of the number and share of knowledge transmitters among the internationally mobile scientists and nonmobile scientists according to research field (cf. Table 1). The highest share of knowledge transmitters among internationally mobile scientists can be found in Earth and Planetary Sciences (48.2%), followed by Neuroscience (45.1%) and Medicine (42.5%).



**Figure 4.** Exemplary network of coauthors citing a reference in astrophysics (based on a real example). The knowledge flow is from sources of knowledge (S), who cited the publication first in 2013, to the transmitter of knowledge (T), who cited the publication in 2015 for the first time, to the recipient of knowledge (R) citing the publication in 2016. The lighter the edge color the later the coauthorship came into being.

**Table 2.** Comparison of the share of knowledge transmitters (KT) among the internationally mobile scientists and the nonmobile scientists according to scientific research field

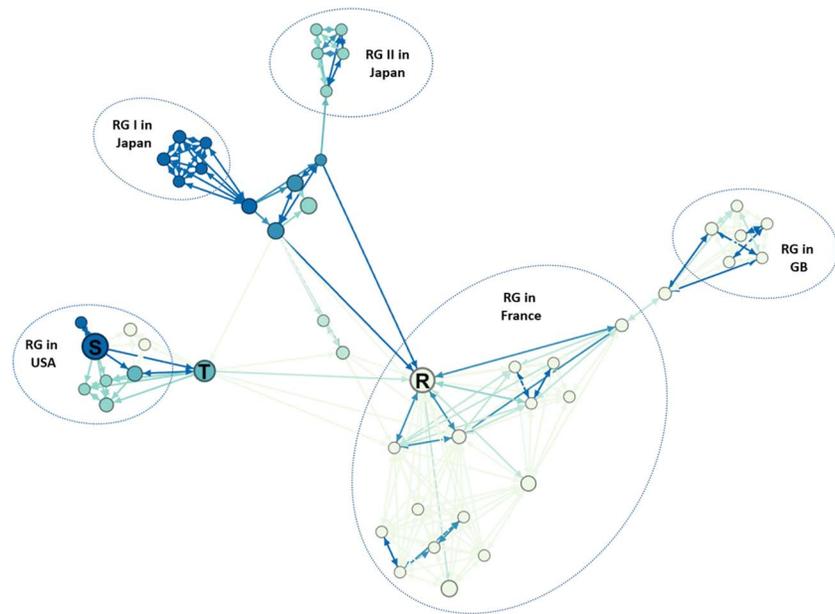
ASJC descriptor	Internationally mobile scientists ( <i>n</i> = 2,937)		Nonmobile scientists (sample of <i>n</i> = 3,000)	
	No. of KT	Share of KT (%)	No. of KT	Share of KT (%)
Medicine	351	42.5	219	26.2
Biochemistry, Genetics and Molecular Biology	127	34.5	103	25.3
Physics and Astronomy	124	26.9	67	20.9
Chemistry	86	34.7	51	17.4
Neuroscience	65	45.1	43	27.0
Agricultural and Biological Sciences	55	26.1	38	13.3
Earth and Planetary Sciences	54	48.2	38	27.3
Materials Science	48	24.7	35	15.2
Computer Science	41	21.4	19	11.7
Engineering	38	21.0	21	12.6

The literature in these fields may be more specific than in other fields and the knowledge about this literature is more likely to be passed on in copresence. Computer Science (21.4%) and Engineering (21.0%) have the lowest shares of knowledge transmitters, suggesting that the transfer of published knowledge as represented by references is not as common as in the other fields listed. At the same time, the number of average coauthors in these fields is comparatively low (cf. Table 1), so that the probability of acquiring knowledge from coauthors and passing it on to later coauthors is lower than in those fields where coauthorship is the norm. The last columns of Table 2 show that the share of knowledge transmitters among the nonmobile scientists is significantly lower than that of the internationally mobile scientists. The share of knowledge transmitters ranges from 11.7% in Computer Science to 27.3% in Earth and Planetary Sciences. We can infer from the results that mobility and thus copresence do not matter in Physics and Astronomy as much as in other fields. Physicists and astronomers are interconnected with research groups all over the world and rather rely on ICT than on physical mobility. In contrast, Earth and Planetary Sciences may require mobility to research groups located closely to places where earth processes such as volcanoes or earthquakes are studied.

#### 4.2. Approach to Identify the Transfer of Methodological Know-how

In this section, the findings of the second approach are presented. The coauthorship network in Figure 5 is based on authors publishing on a molecular biological method for specific proteins between 2003 and 2008. According to interview data and publication data in Scopus, 2003 represents the invention of the method, whereas 2008 represents the adoption of the method in the target research laboratory of the internationally mobile scientist.

The nodes in the network represent authors using the method, whereas the edges indicate the direction of knowledge transfer. The darker the nodes, the earlier the use of the method according to publication year. Figure 5 shows that the internationally mobile scientist from Germany (T) takes on a bridging function in the network by connecting the two research group



**Figure 5.** Directed network illustrating the diffusion of methodological know-how (based on a real example). S represents the research group leader in the US, T the internationally mobile scientist, and R the research group leader in France. The knowledge flow is from source of knowledge S to the transmitter of knowledge T to the recipient of knowledge R. The circles represent research groups (RG).

leaders in the USA and France. The internationally mobile scientist mentioned in the interview that he intentionally moved to the lab where the research group leader (S) had specific research objects and had experimented with the newly developed method. The colors of the nodes represent the year of first use of the method. In 2003 only the research group leader and a coauthor from the lab had a publication on the topic. The interviewee explained that at the same time other research groups were working in parallel on this topic:

...and meanwhile that has exploded. So there are many Chinese and Japanese working groups and Australians who all jumped on these X. That was just a hot topic then, yes.<sup>5</sup>

One Japanese research group (RG I) is represented by the dark blue nodes tied to each other, making up a clique. The lighter blue color of the nodes representing another research group in Japan (RG II) reveals that they published a few years later on the topic. After the research stay in the US, the internationally mobile scientist (T) adapted the method and spent 1 year in France. We can derive from Figure 5 that the research group in France surrounding the research group leader (R) used the method at a later time (i.e., 2008), which is in accordance to the interview data. The size of the nodes shows that the research group leaders and the German scientist have the highest counts of publications on the method in comparison to other actors in the network. The knowledge transfer is directed and underpinned by the edge colors and the arrows from the research group leader in the USA to the German scientist and then to the research group leader in France.

<sup>5</sup> Original interview data: "...und mittlerweile ist das aber explodiert. Also es gibt viele chinesische und japanische Arbeitsgruppen und Australische, die alle auf diese X gesprungen sind. Das war einfach ein heißes Thema dann, ja."

The internationally mobile author is an intercohesive node and thus a boundary spanner. He connects different research groups and was embedded in both communities one after another. In this example, it is likely that tacit and informally communicated knowledge was transferred, because it is inherent to the transfer of methodological know-how.

## 5. DISCUSSION

The findings suggest that it is possible to identify the transfer of different types of knowledge among scientists. Whereas previous studies have operationalized knowledge transfer as citation flows (e.g., Hassan & Haddawy, 2013) independent of time or place, this study pays special attention to international mobility and copresence of scientists. Unlike in previous studies, the networks of knowledge transfer not only consist of the source and the recipient of knowledge, but include a transmitter who is the internationally mobile scientist bridging two research groups located in different countries. Furthermore, this study has shown that different types of knowledge require different operationalization. The first approach is useful to identify the transfer of published knowledge between coauthors. It is unclear to what extent the knowledge in the publication cited was gained, but it enables us to identify at least that knowledge about a publication exists. Drawing on lexical terms, the second approach traced the passing on of methodological know-how among research groups. The copresence of scientists can facilitate the transfer of a newly established method, which is associated with the transfer of informally communicated and tacit knowledge. However, the use of lexical terms also allows the transfer of published knowledge to be identified. A general advantage of lexical terms is that they can represent any object of knowledge (i.e., knowledge about materials, methods, or theories). The choice of terms is crucial, as they are prone to produce false positive results. This can be avoided by the use of unambiguous and rare terms as well as the use of additional information, such as interview data.

There are several limitations to the approaches presented. The number of cases is low because several conditions must be met to reliably trace the flow of knowledge that is operationalized as a triad from source to transmitter to recipient. Another issue is that the less frequent the references or lexical terms are, the lower the number of cases that can be analyzed to detect knowledge transfer.

The main caveat of the first approach is that citing a publication does not necessarily mean that knowledge transfer had taken place, because authors can discover the same publication autonomously. Thus, one limitation is the identification of false negative knowledge transfer, because what looks like knowledge transfer may in reality be knowledge acquired independently. In contrast, methodological know-how is difficult to acquire from publications alone, not to speak of reinventing a method. Unlike in the first approach, coauthorship in the second approach implies that an intense exchange of knowledge and skills has taken place. Other limitations are inherent to bibliometric studies in general. For example, only those mobility episodes that manifest in publications covered by Scopus are tracked. In addition, publications covered in Scopus are not representative of all the knowledge produced by scientists. However, the data delineation as described in the data section should allow for robust data. Of course, there are several factors influencing the route and direction of knowledge transfer between scientists which can escape the use of references or lexical terms (Biscaro & Giupponi, 2014). These intellectual linkages can be also identified by asking scientists to name individuals who have influenced them in the choice of references or research methods. However, directly asking scientists about important influences would lead to naming certain names and omitting others, whereas the network graphs can show all potential influences and a grading of influences.

## 6. CONCLUSION

Knowledge transfer and international mobility shape the careers of scientists and play an important role in the progress of science. Despite the important role that scientific mobility plays in research policy, the knowledge transfer of internationally mobile scientists has been insufficiently studied. This is mainly because tracing the knowledge transfer of scientists is a challenging issue. Currently, there are no all-encompassing methods to indicate knowledge transfer related to scientists' international mobility. Previous studies examined why the transfer of knowledge from person to person did not take place, why different types of knowledge are transferred in different ways, and which factors prevent, impede, or modify the knowledge transfer process between the sources and recipients of knowledge.

The motivation of the study was to determine whether it was possible to trace the knowledge transfer of scientists. To this end, I developed and tested two approaches that are capable of indicating the knowledge transfer of internationally mobile scientists. Moreover, the study aimed at exploring a meaningful visualization and examination of coauthorship networks using empirical data. Coauthorship networks are fruitful not because of their descriptive power, but also because they build on social networks that play an important role in knowledge transfer processes. In the first approach, knowledge transfer was operationalized as the passing on of rarely cited publications between coauthors of mobile German scientists before and after the mobility episode. The results show that the share of knowledge transmitters among internationally mobile scientists is significantly higher than that of nonmobile scientists in each of the fields studied. In the second approach, knowledge transfer was operationalized as the acquisition of methodological know-how. Interview data was used to develop the bibliometric approach and at the same time as a proof of concept.

The findings suggest that references can be used to study the transfer of published knowledge, whereas lexical terms can help to study the transfer of methodological know-how. The combination of lexical terms is powerful and can be used to represent any kind of knowledge. Often scientists adopt knowledge without being aware of the source of the knowledge or may perceive that they have not gained new knowledge. In this case the knowledge transfer networks could be used to underline the relevance of international mobility in terms of knowledge acquisition and transfer. Apart from mobility across borders, the approach can be used to study mobility across institutions within a country, across different sectors, or among research areas.

One challenge of the approaches is to make sure that the knowledge transferred can be traced back to coauthors and is not acquired independently. The restriction to coauthorship networks can be seen as a limitation. Future research should aim at delineating coworkers of internationally mobile scientists who are not necessarily coauthors, but can nonetheless act as transmitters of knowledge.

The underlying study is one step forward in improving our understanding of knowledge diffusion networks. The identification of knowledge transfer among scientists and countries can give rise to interesting analyses and has potential to become an indispensable science indicator. In further studies in this area, I will focus on the tacit knowledge dimension that can be uncovered by studying the passing on of lexical terms.

International mobility not only serves an individual scientist's interest, it also enriches the entire scientific knowledge base in a research field by enhancing the knowledge flow across different actors and places. Therefore, it remains important to think of further methods to examine whether and how international mobility leads to knowledge transfer and to develop more powerful and explanatory visualization techniques.

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## COMPETING INTERESTS

The author has no competing interests.

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## DATA AVAILABILITY

Bibliometric data cannot be made available due to licensing contract terms. Interview data cannot be made available for reasons of confidentiality.

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