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# Mutual Linguistic Socialisation in Interdisciplinary Collaboration

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## Abstract

This chapter examines the deliberate efforts of mutual linguistic socialisation carried out by paleoclimatologists and paleo-modellers through which they seek to improve communication between both communities. These efforts include the creation of Summer Schools and Graduate Programmes where students learn from experts from both fields, the joint supervision of PhD students by paleoclimatologists and paleo-modellers, informal conversations at conferences and in collaborative projects, and university departments with academics from both research areas. I argue that most of these initiatives do not result in individuals acquiring a high level of linguistic competence in the domain that is not their own, i.e. interactional expertise (IE). Yet, these efforts can still help bridging communicative gaps between paleoclimatologists and paleo-modellers.

## Introduction

Language is a central topic in studies of interdisciplinary scientific communication and collaboration. Importantly, Science and Technology Studies (STS) have revealed that different scientific communities frequently seek to develop some degree of mutual understanding in order to improve their collaborative efforts (Galison 1996, 1997; Jeffrey 2003; Shrager 2007; Collins 2011, Reyes-Galindo, 2014b).[1] STS cases studies that have focused on the development of mutual understanding have concentrated on explaining how scientists working in particular projects develop linguistic skills to mediate communication while their communities remain largely uninformed about the language that is not their own (e.g. Galison 1996; 1997; Monteiro and Keating 2009; Collins 2011; Reyes-Galindo 2011, 2014b; Shrager 2007).

Here I explore a case in which two communities – paleoclimatologists and paleo-modellers – have engaged in a deliberate effort to mutually linguistic socialise each other to improve their collaborative efforts. In other words, paleoclimatologists and paleo-modellers make continual efforts to increase community members' competence in the language of the field that is not their own and to train the new generation of scientists to have a better linguistic understanding of both areas. Even though in some cases members of these fields learn a few skills from the other domain, most efforts focus on learning solely the language. They are thus not seeking to become 'contributory experts' (CE) in each other's fields (Collins and Evans 2007), i.e., to learn the skill-sets to be able to produce data, model output, and so on. Their efforts are directed at acquiring linguistic competence to mediate communication between them.

Existing STS literature describes how in similar cases scientists use different levels of linguistic competence to communicate in collaborative projects. Studies have shown how scientists can acquire a high level of competence in the language of another domain to facilitate communication in collaborative projects (Shrager 2007; Reyes-Galindo 2011). In other words, they acquire 'interactional expertise' (Collins and Evans 2002, 2007, 2015; Reyes-Galindo and Duarte 2015), which consists of the mastery of a language.[23] Working from a different angle, Galison (1996; 1997; 2010) has pointed out that frequently scientists develop interlanguages, i.e. a combination of speaking in simplified registries with the merging of concepts of the languages of the scientists involved in the collaboration, to facilitate communication. Interlanguages are typically used in situations in which members of a collaborative project do not have such high linguistic understanding of each other´s field.

In this chapter, by examining the interactions between paleoclimatologists and paleo-modellers, I seek to elucidate what level of linguistic understanding is the result of these communities' efforts at mutual socialisation. I argue that in most cases members of these communities do *not* have enough immersion in each other's domain to acquire interactional expertise (IE). This process thus results in individuals developing lower levels of competence than IE in the language of their collaborators.

This point leads to the issue of how one can distinguish between IE from lower levels of linguistic understanding in real research settings. As the acquisition of expertise depends on a process of socialisation in the community of relevant experts (Collins and Evans, 2007), this question directly relates to how much linguistic immersion one has had in the community´s discourse. As IE consists of the mastery of the language of a field of expertise, a long process of immersion in the form of life of the expert field is a *sine qua non* for its acquisition. Scientists only master their own domain languages after years of training and supervision by senior experts. It is usually only after they finish their PhDs that they will be able to speak it at such high level of competence. Therefore, in the case of scientists acquiring IE in a domain which is not the one in which they have CE, it also takes several years of immersion for them to completely master it. This process tends to happen in the following way. A paleoclimatologist who has never talked, and/or listened to paleo-modellers speak about their work, has no IE in their language. If she starts collaborating with a group of them in a project in which she has only a few informal conversations to clarify very basic points, she will start to acquire linguistic competence in their language. If the initial project leads to a longer one involving, for instance, a weeklong workshop and regular conversations at university offices/corridors or through skype, the paleoclimatologist will significantly raise her competence in paleo-modelling language, but will still fall short of being an interactional expert. If the collaboration goes on for several years, including several workshops, joint panels at conferences, extensive informal conversations, and so on, she might become so fluent that she will become indistinguishable from paleo-modellers when speaking about their domain. At this point, she will have mastered their language and will have reached the level of interactional expert.[4]

This chapter is based on the methodology of participant comprehension (Collins, 1983, 1984, 2009; Reyes-Galindo, 2014a), which has been used in a number of STS studies (e.g. Collins, 1992; Pinch, 1986; Reyes-Galindo, 2011, 2014b; Ribeiro, 2007a). The methods deployed were semi-structured interviews and participant observation. Forty scientists based at British universities from different nationalities[5] were interviewed, including paleoclimatologists, paleo-modellers, and experts from adjacent domains, such as geochemistry and micropaleontology. Some interviews were followed up by email exchanges with the interviewees to clarify particular points that emerged as interesting when examining the interviews´ transcripts. Participant observation included attendance at research seminars, international conferences, and an international summer school with experts from all over the world, and visits to laboratories in two British institutions.

**Paleoclimatology and Paleo-modelling**

*Paleoclimatology* is an amalgam of disciplines whose main goal is to reconstruct past climate, particularly from periods before the emergence of consistent climate records.[6] It is an empirical science that deploys a number of geochemical, micropaleontological, and sedimentological techniques, which are known as climate proxies, to work out how the climate system worked in the past. *Paleo-modellers*, on the other hand, use computer models to simulate past climates. This is an area of science that is not involved with the generation of empirical data, although empirical data is fed into climate models. The expertise, epistemic culture (Knorr-Cetina 1999), and the research instruments used by members of these domains are considerably different.

As I have described elsewhere (Duarte 2013), these fields are subdivided into several sub-domains. Paleoclimatology is made up of scientists who specialise on particular archives (marine sediments, ice-cores, tree-rings, corals, and so on), techniques, time intervals, climatic phenomena, amongst others. These experts do not master each other's' languages as there is too much diversity within the field. For this reason, they tend to have a lower understanding of other subspecialties of paleoclimatology than those immersed in each of them. For example, paleoclimatologists specialised in time intervals of millions of years ago are not likely to have a high level of understanding of archives such as tree-rings, which can hardly produce data from much beyond a few thousand years back in the past. Yet, their understanding of tree-rings is still much higher than of those who are not paleoclimatologists due to their formal training. In this sense, conversation between experts specialised in different time intervals may be mediated by changes in registry (Galison 1997, 2011) or trust (Shapin 1994; Shackley and Wynne 1995; Reyes-Galindo 2014b). In specific projects in which they deem necessary a high level of linguistic understanding, they may look to acquire IE in each other´s practices.

The same happens with paleo-modellers. They also tend to specialise in particular types of models (e.g. statistical modelling, box-modelling, Earth system models, etc.), climatic phenomena, time intervals, and so on. Each of these specialisations entails a high level of understanding of particular subspecialties, which modellers with other contributory expertise will not have. Similarly to what has been argued above about paleoclimatologists, their communication might be mediated by changes in registry or trust. IE is acquired only in particular collaborative projects in which participants feel the need of a higher level of understanding of their collaborators´ subspecialties.

**Trade at work: Collaboration between paleoclimatologists and paleo-modellers**

Paleo-modellers and paleoclimatologists currently have strong collaborative ties. They setup different types of collaboration depending on the goals of specific research projects. As pointed out above, paleo-modellers feed paleoclimatological data into their models.[7] In these cases, they collaborate with paleoclimatologists who review the literature and compile data for them.

Paleoclimatologists usually become interested in collaborating with modellers to test different hypotheses they have developed to interpret their data. They sometimes are unsure about which variables have triggered a climatic process. Several hypotheses might be held and the data alone cannot provide answers as to which one is the most plausible. There are several feedbacks in the climate system and sometimes it is difficult to identify which variable was the cause and which variables were the feedbacks of a given event. In these situations, paleoclimatologists sometimes collaborate with computer modellers who simulate how the Earth system reacts to alterations in different climatic variables. The models then provide insights on the plausibility of particular hypothesis. Paleoclimatologists also collaborate with modellers to select where to collect data. In order to work out which areas are particularly sensitive to certain types of environmental changes they sometimes use models output to refine strategies for data collection.

**Paleo-modellers and interactional expertise in paleoclimatology**

According to some paleo-modellers interviewed for the project, it was only in the 1980s that climate modellers became interested in modelling paleoclimates. At this point, they were outsiders stepping into a different field of science and willing to contribute to it. I will not reconstruct the history of paleo-modelling here as this falls beyond the scope of this chapter. It is important however to point out that paleo-modelling emerged when computer modellers became interested in past climates. Most had a background in mathematical physics. To model paleoclimates they had to learn a great deal about the history of the Earth system, about the main mechanisms of change in the Earth system in geological time scales, and about the different data sets available on past climates, which are the main elements that constitute the language of paleoclimatology (Duarte, 2013). As pointed out above, paleoclimatology is a heterogeneous domain that has many subspecialisations. Modellers would therefore not be able to acquire a high level of understanding of the whole history of the Earth, of all mechanisms of change of the Earth system and of all different proxy systems used to generate paleodata. They therefore had to acquire a high level of understanding on those particular climatic phenomena they were intending to simulate, the time intervals they were interested, and on the archives and proxies that could be used to study them so as to be able to do their modelling effectively. As a result, there is an overlap in the language spoken by members of these communities interested in similar phenomena and time intervals that mediates communication between them:[8]

> Emma: When you're working with climate modellers that are interested in similar problems that you are, it's pretty straightforward because they might actually know what you're doing. They might know some of the literature that you know. So, they know the problems. In this case of James [a paleo-modeller Emma worked with], he knew perfectly the context and we were working on the same time interval.

Although there is this overlap, there is difference between these communities as well. Modellers began to learn about paleoclimates, but differences remained in their technical languages. Most modellers, for instance, have not become immersed in the literature on data generation. When they read the paleoclimatology literature, they tend to focus on new interpretations of paleoclimatic phenomena rather than on the details of data production. The following quotation from a paleo-modeller who had been immersed in the paleoclimatology community for around twenty five years talking with its members and co-authoring papers with them illustrates this point. He states very straightforwardly that he does not keep up with the literature on data generation. He tries to keep himself up to date with the literature on paleoclimatic processes and by going to conferences he keeps his knowledge on the major trends in data production up to date:

> Louis: The things I don’t keep up with particularly on the literature is actually things like the actual data collection because obviously there are loads of data coming in from around the world in terms of all different aspects. That’s one of the things I do, I think it’s quite natural for paleoclimate modellers. […]. One of the things I use conferences for and yesterday, the past two days, was a good example, because by going to conferences you get a good synthesis of what’s going on. And that’s the only way I can cope because I can’t follow every individual, I don’t read every single data collection for the early Eocene. But what I do do is I go to conferences where I hear Jim Zachos summarise the data for the early Eocene and that’s actually what I need because that’s the only way I can work. It’s this big-picture level.

However, he still has a high level of linguistic understanding of the proxy systems used to generate data that came from his immersion in the paleoclimatology community associated with collaborating with some of its members, as this extract from an email conversation I had with him reveals:

> Louis: I believe I have a good critical understanding of these [well established] proxies, such as oxygen isotopes or palaeobotanical indicators (which both can produce quantitative estimates of climate), and sediments (which produce more qualitative estimates of climate, such as wet summers) for two reasons. Firstly, they have been around for a long time and therefore I have been exposed to a lot of the discussions on their strengths and weaknesses. In addition, because I have been working in this subject or almost 25 years now I have often been around when they were being developed/refined and when here is debate in the community, that is the best time for learning their strengths and weaknesses. Another reason I feel comfortable with these proxies is that I have worked and published comparisons of the proxies with my model output, normally working with leading scientists working with these proxies and the discussions associated with such work has left me well understanding the data.

The fact that Louis has a high-level of linguistic understanding of proxy systems, but does not follow the paleoclimate data production literature closely should not be taken as meaning that he does not have IE in paleoclimatology. A study of the role of mathematics in physics helps clarify this point. Collins (2007) found through a survey he carried out in four different physics department that the majority of physicists, when reading scientific papers from their field, do not typically perform a step-by-step check of the mathematical equations which are used to prove the main points. They either skip the maths part and assess the paper in terms of whether it makes sense according to the rest of the literature or have a quick look at the equations only to have a sense of what direction the mathematical reasoning follows. In this sense, when reading papers they tend to privilege a conceptual reading over following in detail the generally complex mathematical proofs.

Returning to the collaboration of paleo-modellers and paleoclimatologists, if we transpose the lessons from Collins' to this case study, there is no reason why one should expect interactional experts in paleoclimatology to follow the entire paleoclimatological literature on data generation. What an interactional expert needs is a conceptual understanding of how data is generated, i.e. the principles behind each proxy. If there are specific issues with particular data sets, it is not up to interactional experts to detect them, but to contributory experts who master the relevant techniques. Then, these issues will spread to the rest of the community through linguistic exchange, be it written or spoken.

Having made this point about some paleo-modellers having acquired IE in paleoclimatology, it is worth noting that, differently from Louis, who have been collaborating with paleoclimatologists for over two decades, several of them have not reached a high-level of understanding of data production in paleoclimatology. The following modeller is an example of this:

> Roger: […] And just from various conferences and meetings and things. That is when I started really learning a lot about the paleodata. Although I would say that if you've been to [the] Urbino [Summer School in Paleoclimatology] you probably know a lot more about the paleo-data than I do (laughter). I'd never been there and still my knowledge of paleo-data is somewhat lacking.

These variable levels of understanding that paleo-modellers have of paleoclimate data are the main reason why members of these communities believe that a process of mutual linguistic socialisation is necessary to improve their communication. But, before examining this process, let us have a look at the paleoclimatological community and their linguistic understanding of paleo-modelling.

**Paleoclimatologists and interactional expertise in paleo-modelling**

The emergence of the collaborations between members of these communities is also related to a wider phenomenon taking place in climate science. Similarly to what has happened in the whole of climate science (Demeritt, 2001; Edwards, 2010; Jasanoff and Wynne, 1998; Shackley et al., 1998), computer modelling has grown in importance in paleoclimatology over the past two decades. In climate science, it is argued that, as it is impossible to run experiments on global climate change, models are the best tools available. They enable scientists to bring together data from all over the world and run tests on them. As pointed out above, similar reasons have influenced paleoclimatologists to collaborate with modellers, i.e. the possibility of testing hypothesis on how to interpret particular data sets. Consequently, a significant number of paleoclimatologists became interested in collaborating with modellers. Their work was facilitated by the fact that modellers were already trying to acquire linguistic competence in their domain. As I have mentioned above, paleomodellers had already acquired a high level of linguistic understanding of the mechanisms of climate change in geological time scales that were related to their research interest and in the parts of the history of the Earth relevant to their projects. Furthermore, paleo-modellers were also acquiring variable levels of linguistic competence in the principles underpinning the generation of paleoclimatic data that was particularly relevant to them. This created some overlaps in the languages of these fields which helped communication.

However, for paleoclimatologists to collaborate effectively with modellers they also had to learn about paleo-models. The following quotation exemplifies what paleoclimatologists sought to acquire a linguistic understanding on:

> Tiago: So, when you collaborate with modellers to which extent do you try to be well informed about the [model] codes?
>
> Robert: Not the codes because I don't have time to be able to go into the code and identify sub-routines that relate to the coupling of ice sheets to Antarctica temperature or something. There's no time to do that. But what I seek to understand is, I ask lots of questions to modellers because I want to know what they've parameterised, what are the weaknesses, what are the strengths, what are the things that we may need to carry out a sensitivity test on them. What is the physical-evidence base to support the way in which the model's been built.

Similarly to what I have argued above about IE in paleoclimatology, i.e. it does not include following in detail the data production literature, in the case of IE in paleo-modelling paleoclimatologists are not expect to acquire any understanding of the model codes. Understanding model codes is part of the contributory expertise in modelling. If there are issues with them, contributory experts have to deal with them and the issue spreads in the community through language.

The level of understanding of paleo-modelling acquired by individual paleoclimatologists depends on how close and lengthy their collaborations were. As I will point out below, some paleoclimatologists were hired by paleo-modelling departments to help bridge the gaps between these fields. In these cases, paleoclimatologists can potentially become IE in paleo-modelling if they work in these departments long enough. In other cases, paleoclimatologists have a very low linguistic understanding of paleo-models or no understanding at all as the following quotation shows:

> Isabel: Yes, I know that models have lots of uncertainties and they make a lot of assumptions. Unless you are in that field you just don't know what they are. And I'm learning at the moment, because I just started this new collaboration with modellers now, I'm learning what some of this assumptions are. You could easily have a career in paleoclimatology and not understand all the assumptions that go into climate models, because it's such a distinct field.

Thus, similarly to what happens with paleo-modellers when it comes to understanding the different proxy systems used in paleoclimatology, paleoclimatologists have variable levels of understanding of modelling. The widespread perception that several paleoclimatologists still need to have a much better linguistic understanding of paleo-modelling has also contributed to the deliberate effort of these communities to enhance each other´s linguistic understanding through the process of mutual linguistic socialisation I will describe in the next sections.

**The mutual linguistic socialisation process: formal courses**

As part of the mutual linguistic socialisation process that is being carried out by these communities, there is an effort to educate the new generation of paleo-modellers and paleoclimatologists in both fields. These efforts, however, are not the same as those made to socialise students to become contributory experts in their own domain, which involve a great deal of hands-on activities - such as laboratory practice and fieldwork in the case of paleoclimatologists and computer programming and debugging in the case of modellers - and the continual supervision of senior academics. In this case, socialisation is mainly linguistic involving to a much lesser degree practical activities. The ultimate goal is for graduate students to acquire a higher linguistic competence in both data production and modelling than that of the current generation of scholars, i.e. something much closer to IE, although as I will argue below, the evidence is that this level of understanding usually cannot be reached through the means used by this communities. Two main types of efforts of mutual socialisation are being currently deployed: the creation of formal courses where students learn about paleoclimatology and paleo-modelling and the shared supervision of PhD students by members of both communities.

The Urbino Summer School in Paleoclimatology[9] was designed with the objective of providing a basic training for the new generation of paleoclimatologists and paleo-modellers in both areas of investigation. In this yearly event, which started in 2003, around thirty experts with different expertise, including paleoceanographers, micropaleontologists, geochemists, paleo-modellers, working on the whole range of geological time intervals and using a variety of techniques, lecture for three weeks graduate students with background in data generation and in paleo-modelling. As a result, young researchers receive basic linguistic exposure to areas of expertise which were not their own. Furthermore, there is great deal of informal socialisation in this event, as students and faculty frequently go out together for dinner and for drinks.

It is not possible to provide a precise measure of how much linguistic competence is acquired by students there as this depends on the background of each of them, on how seriously they take the lectures, and on how frequently they engage in informal conversations about science with faculty members and with other students. As the summer school lasts three weeks, it is not expected that they will in this period become IE in any subfield of paleoclimatology or paleo-modelling that is not their own, as this would need a much longer immersion in the relevant communities. But it provides them with at least a general overview of most subareas of these fields.

During the summer school, there are also a few practical activities, such as a field trip, in which all participants make measurements and write the log of an outcrop, and some exercises such as filling out spreadsheets to develop age models for sedimentary cores, solving geochemical equations, and writing the commands to run a paleo-model. In this sense, the students also experience physical immersion (Ribeiro 2013) in some of these domains' practices. These activities, however, are very short and much less time is spent on them in the Summer School than the formal lectures so that they are not enough for anyone to become contributory or interactional experts in any of them. Yet they are an opportunity for the students to have further linguistic socialisation in both domains as they have the opportunity to ask further questions that would not be brought up if they were not doing these activities under the supervision of experts (Ribeiro 2013).

Universities such as the MIT and the University of Bristol have also developed courses where students have training in both paleo-modelling and paleoclimatology. These initiatives were deliberate and reflected a collective sense that interactions between the modelling community and paleoclimatologists could be improved. A geochemist who applies his expertise to address paleoclimatological problems described a joint Masters programme where students are trained in modelling and in producing data. The initial motivation for setting up this course was a frustration caused by difficulties in communication between paleo-modellers and paleoclimatologists:

> Tiago: And how are these new collaborations going on?
>
> Tim: They're good. I find that *there's sometimes a slight communication problem* so I decided to do something about this. We have a Masters programme here in Earth system science, which I've just taken over and we just started really. And the philosophy of this Masters course is to produce people who will hopefully go on to a PhD who have a basic training, *it can only be a basic training in both modelling and the observational side of science*. And the main reason I'm interested in doing this is that

> *I find that there's sometimes gaps in understanding on both sides that lead to problems*. So, in order for a modeller like Bruce to model, he models neodymium isotopes in the ocean, he needs to understand how the basic chemistry works, how it all works. Anyone who does that needs to understand. Many modellers do and some don't actually. The relationships are relatively easy to start and build but also require some effort in educating each other. Because I'm also ignorant about what exactly a model can do very often I find. I call them up and say let's do this and usually you can't do that, that would cost years of computing time (emphasis added).

The students receiving training in both areas is a deliberate attempt of these communities to intensify the links between these fields. Again, this is not going to make any of the students contributory or interactional experts in all these practices. As Tim points out in the quotation, they receive only a *basic* training in modelling and data production. Similarly to what happens in the Urbino Summer School, what is at stake here is learning these domain languages at a simplified registry, not at an expert level.

**Mutual linguistic socialisation: joint supervision**

Another mechanism that is being deployed by these communities to enhance mutual socialisation is the joint supervision of PhD students by paleoclimatologists and paleo-modellers so that their doctoral research includes modelling and data generation. In this case, similarly to what has been argued in the previous section, these students do not become experts in both fields. Becoming a contributory expert in a scientific domain involves experiences that fall beyond formal training, i.e. lectures and general coursework, and requires a process similar to apprenticeship in medieval craft guilds (Charlesworth et al., 1989: 92-93). It is necessary to spend years acquiring tacit skills under the supervision of senior researchers to become fully accomplished in the practices of a scientific domain. As Mody and Kaiser (2008: 385) have pointed out,

> only after extensive practice, drawing on a combination of text-based and tacit routines, do research skills become second nature for new technical trainees. Only after intense pedagogical inculcation do new recruits develop the 'disciplined seeing' or 'hands' of accomplished practitioners (Goodwin, 1994, 1997; Doing, 2004; Mody, 2005).

In addition, acquiring CE in two domains is within a PhD timeframe is a highly challenging enterprise that may lead students to face serious difficulties:

> Karin: I've got one student who is doing her thesis on both geochemistry and modelling. It's a big deal. I'm not sure we should do that again actually. I think it should be one. It's frustrating from all perspectives because there are two PhDs there. But she wanted to do it like that, so she has only herself to blame. But that's unusual. Typically, if they are data people there's usually a component of modelling, if they are modellers there's usually at least a component of data compilation.

The research project of the students receiving training both in paleo-modelling and paleoclimatology thus is usually in one of these fields and has a smaller component of the other. They acquire a general linguistic understanding and very basic practical skills in the area that is not their main one.

Modellers might, for instance, compile data to put in their models. They might also go to the field with a supervisor who has expertise in collecting data. They will then collect samples and generate data on them. However, as there is too much specialisation involved in becoming a full-blown data generator, they usually do it under the supervision of their supervisors and do not become fully accomplished in the 'data side' at the end of their PhDs. A paleoclimatologist who is very skilled in sedimentology described to me how she co-supervised PhD students with climate modellers:

> Karin: What I have that my modelling colleagues don't have in fact is field skills. I actually worked as a professional field geologist for five years. So, I know an awful lot about interpreting rocks and sediments in the field. I have taken three of my current set of students out into the field and taught them what it is that you need to look for, how you log, how you map, how you take samples, trying to give them exposure to the rocks that actually they do their analysis on, or the sediments from which their data are drawn whether they are published or whatever. So, I do quite a lot of that. I try and teach that as much as I possibly can in the field. […]. I have a commitment to make sure my students, and simply that they couldn't do it without me there because they simply don't know how. […]. These are students who come from very, very, varied backgrounds but the thing they tend not to have is the geology and so I do that.
>
> Tiago: And is it a bit like an apprenticeship?
>
> Karin: None of them do, because if they actually had a field-based PhD I would have to take on someone with an Earth Sciences background. So, none of them have a huge component of fieldwork in their projects. So, actually what you're doing mostly is you're training them, *but in the time available they will never be competent to do the job*, which sounds a bit snide, but that's just the way it is. They are never going to be field geologists. But they need to understand how the field data side is done.[…]. *So, is it an apprenticeship? No, because they don't actually get to be proper field geologists*. (Emphasis added).

These PhD students at times play a role similar to that of 'interactional ambassadors' in large physics collaborations (Collins, 2011; Reyes-Galindo, 2011, 2014b). These individuals (usually PhD students) are purposefully trained to be points of contact with other research groups. In these projects, when a group of scientists depends on knowledge or data produced by another group whose language and techniques they do not master, researchers are sent to spend some time working with the other group. The idea is that through this immersion these ambassadors acquire some level of linguistic competence in the other domain – how high this level will be will depend on how long the immersion is. When they come back, they can then help their original group by answering technical questions and queries related to the work carried out by the group they visited.

In the case of the paleo-modelling PhD students being jointly supervised by paleoclimatologists and paleo-modellers, they end up with only a basic understanding of what paleoclimatologists do. Yet they can still contribute, even if modestly, to the process of building bridges between paleoclimatologists and paleo-modellers by explaining to their groups the basics of what scientists from the other domain do:

> Karin: For instance the one [modelling PhD student] I went to Morocco with has actually given a talk to the group. What she wanted to do was to write a talk that was specifically about how the fieldwork was done because she had never done it and she was quite right in thinking that actually there’s nobody else in the department who knows how it’s done either. So, she’s done things like, she’s taken a picture, a photograph, of a section, and she then merges my sketch of it to show what it is that I’m picking out of that. And then she takes a picture of a logged section and then shows my log alongside and correlates it across.

Interestingly, in terms of the mutual socialisation process, what really matters in this example is the linguistic understanding these students develop of how paleoclimatologists do fieldwork, as it is only this understanding that is shared with their research groups. They acquire too little hands-on skills to deploy in the field so that they cannot train other modellers to do fieldwork proficiently.

**Mutual linguistic socialisation in scientific events and in research projects**

Despite the mutual socialisation efforts described above, there remain difficulties in communication between these communities. Firstly, because more senior researchers have not received training in the domain which is not their own like the younger generations. Secondly, because the mutual socialisation process cannot provide the new generation of scientists with a high linguistic understanding of all sub-areas of paleoclimatology and paleo-modelling. In fact, none of the examples presented above provided students with opportunities to acquire IE in both fields. The remaining gaps between paleo-modellers and paleoclimatologists are bridged through reading the literature, talking, and attending conferences. Reading the literature is an important part of this process. However, reading the literature alone is not enough for being socialised in a domain as scientific papers cannot convey tacit knowledge (Collins and Evans, 2007; Weinel, 2010). For an individual to really improve his or her knowledge through reading the literature it is necessary for him or her to have a sense of what papers are regarded as the most relevant, what papers are outdated, what techniques have been improved, etc., which can be learned through linguistic socialisation. A large part of this mutual education is done by attending conferences and by talking to relevant experts. This point is exemplified by the following geochemist:

> Tiago: How do you think this mutual education would work in practical terms?
>
> Tim: It just works by conversations in the corridor, going to seminars, I go to modelling seminars, Bruce [a modeller] goes to data seminars.

In the quotation on page 9, Louis makes a similar point. Louis is a senior modeller who does not have enough time to follow the entire literature on data generation and points out that he tries to keep himself up to date with the paleoclimatic literature by going to conferences.

I have attended two conferences and a research seminar in which paleo-modellers and paleoclimatologists were presenting papers in the same room, asking each other questions after the presentations, and chatting during coffee breaks. In these chats, different scientists presented their views on particular papers, either supporting or criticising them. In some cases, some experts would ask other scientists to clarify points they had not really understood. These events are thus important occasions for scientists from these fields to acquire, to keep their linguistic understanding in each other's domain up to date or even to increase it. The same happens in summer schools. For example, during an informal conversation with a professor of micropaleontology about the Urbino Summer School in Paleoclimatology, he said that the event was very productive for faculty because they could spend a great deal of time with other members of the community talking informally. He also pointed out that many papers emerged out of these informal chats. A paleo-modeller said the same during a lecture.

In specific projects, scientists might also need to acquire higher levels of linguistic understanding of the domain which is not their own than they have. Modellers might need a deeper understanding of the data they are working on in terms of their uncertainties, caveats, etc. Paleoclimatologists, on the other hand, might need to better understand the models their collaborators use. This is necessary for them to be able to interpret their output and link them to their understanding of the Earth system. The following quotation from an interview with a paleoclimatologist exemplifies this point:

> Tiago: You said that you are learning about climate models now. How are you going about this process of learning?
>
> Kate: Just by talking to the modellers themselves and learning what they need as a kind of input parameters into the model, so how they estimate what vegetation was like 40 million ago, how they estimate what latitudinal temperature gradients were. There are so many different types of climate models and some of them you prescribe a lot of variables right there and then others the model is so complicated that you just fix a few variables at the beginning and then the model itself predicts things like vegetation and what have you. It's different kinds of plug-in components you can put in. But, when you read the modelling literature unless you are in the field it's difficult at first sight to know how much exactly of the output of the climate model are totally free and how much has been driven partly by what they assume or what they prescribe at the beginning. So, those are the kind of things that I'm learning, which of course is essentially an understanding of how good those predictions are.

The following paleo-modeller made a similar point:

> Mary: I think that one of the safest things to do is to involve the person that's made the data in your work, closely. For example, I have a piece of work with Jackeline at the moment, because we're using her data very closely. And we've created a relationship because of these science questions. That's a very good way of doing it. Otherwise I think that you have to read very broadly, and if you can't work with the person, phone them, email them, find someone working on very similar things and discuss it

> as far as you can, and really work hard to really understand the shortcomings rather than simply using it.

In sum, besides the mutual socialisation that is taking place between paleoclimatologists and paleo-modellers, there are also individual efforts made by members of these communities to increase their levels of linguistic understanding of the domain that is not their own. Most of them seek a simplified understanding of the instruments, practices, and data of their collaborators that is enough for them to make collaborative projects work. But, if they spend a long time collaborating with particular groups and therefore being linguistically socialised by them, they can potentially become IE in their domain.

**Mutual linguistic socialisation: ambassadors**

The notion of ambassadors, which has already been mentioned above, can further help us understand the process of mutual linguistic socialisation between between paleoclimatologists and paleo-modellers. For instance, a department composed of several paleo-modellers hired two paleoclimatologists to help them carry out model-data comparison. In this case, these paleoclimatologists were bridging the gaps between these communities with a combination of their contributory expertise, which was valuable in collaborative projects, with linguistic understanding of modelling that they acquired by consistently interacting with paleo-modellers. The following quotation is from an interview with a paleoclimatologist who plays this role:

> Karin: I don't do any modelling. I do generate data. But quite a lot of the work since I've joined this department is about data modelling comparison and is trying to bridge that gap.
> […].
> As I said when I moved here I was brought in to be the kind of deep-time data person for this modelling group. And I have therefore done some work with them on things like, yes, model-data

> comparison, and compiling data sets so that they can test their models in a meaningful way, trying to incorporate elements of data generation into models in order to make that comparison more robust.

This ambassador spent a great deal of time immersed in this group of modellers. She did not acquire contributory expertise in modelling, but could communicate really well with her colleagues:

> Karin: I don't really have problems communicating with modellers because actually I understand what it is they're after. I sometimes don't think they scrutinise the data hardly enough. But that's not the same thing as not understanding what they are after.
> […].
> The thing is that I actually do, I'm at that interface, and I'm pretty unusual in that respect because my data gets put into models and is used by modellers. I don't think that many people are on that interface, but I am.

## Conclusion

In this chapter, I have examined the mutual linguistic socialisation process that is currently being conducted by paleoclimatologists and paleo-modellers. Although members of these communities have been collaborating for over twenty years, few of them have become full-blown interactional experts in the specialty of their collaborators. There is a feeling among them that it is necessary to improve their general level of linguistic competence in the domain which is not their own. I have argued that most efforts involved in this process of mutual linguistic socialisation leads to a limited understanding of the language of their collaborators. There are only a few situations that may provide individuals with the opportunity to develop IE, such as the case of ambassadors analysed in the previous section.

Yet one should not conclude that this process of mutual socialisation is in vain. Firstly, if particular members of these communities feel the need to acquire IE in the domain which is not their own, the mutual socialisation process will already have put them in an advantageous position if compared with those who have not had the immersion they had. Secondly, even if they are not reaching the level of interactional experts, their increased understanding of the other domain may help mitigate misunderstandings in collaborative projects. Monteiro and Keating (2009:19-20) have argued that in interdisciplinary projects misunderstandings should not be solely seen as unproductive, but as occasions that can give rise to opportunities in which erroneous interpretations and unshared assumptions might be identified. As a result, shared understandings might emerge. In spite of agreeing with them, it is much more advantageous if scientists already have from the outset a higher understanding of each other´s domains so that they do not have to go through "productive misunderstandings" to start communicating effectively. In this sense, although the process of mutual socialisation presented in this paper cannot avoid these occasions altogether, it can at least prevent some of them, making interdisciplinary collaboration less challenging for these communities.

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[1] Nevertheless, these studies also conclude that highly developed shared frames of meaning are not a precondition for effective collaboration. Star and Griesemer (1989) have made interesting contributions to how cross-disciplinary research may benefit from a lack of shared frames of meaning.

[2] Although interactional expertise has gone through a development process since it first appeared in a paper in 2002, it is currently understood as the mastery of the language of a field of expertise (Collins and Evans 2015; Reyes-Galindo and Duarte 2015). In this sense, despite the fact that IE has been used in some contexts to refer to low or medium levels of linguistic understanding (e.g. Collins 2011; Duarte 2013), its definition is clear that it consists of a high level of competence in a specific language. Its usage to refer to situations in which individuals only have a low or medium linguistic understanding of a field of expertise therefore is not coherent with its definition.

[3] According to Collins and Evans (2002, 2007), one can acquire interactional expertise in any set of practices that require a minimal amount of skills to be carried out, including activities as varied as speaking a natural language, gardening, guitar playing, football, and science.

[4] Collins and Evans (2014) claim to have developed a new methodology, the Imitation Game, which can distinguish interactional experts from people with lower levels of linguistic understanding of a particular field of expertise. I have not had the opportunity to use this method with paleoclimatologists and paleo-modellers to assess if they had acquired IE in the domain of their collaborators.

[5] This included British, German, Uruguayan, American, French, Dutch, Danish, and Spanish researchers. The sample included people with research experience in all major countries where paleoclimatological and paleo-modelling research is carried out.

[6] The timescale of the instrumental record is short extending only approximately 150 years back into the past (Burroughs, 2001: 140-151). Satellite measurements have only been carried out since the 1960s. Instrumental measurements have been conducted for a longer period, although it is still short if we consider the geological time scale, which extends a few billions years into the past. Temperature measurements, for instance, have been taken for up to 300 years, but with scattered geographical representation. Land temperature measurements were carried out only in parts of the northern hemisphere until the late nineteenth century, when an increasingly broader coverage gradually reached other areas of the planet. It is only by interpolating records that it is possible to reconstruct land temperatures back into 1860s. Sea-surface temperatures have also been measured since approximately 1860 with buckets that collected water from the side of ships. The coverage was also scattered as only the main ship routes have consistent records.

[7] Paleo-modellers use these data in three ways. Firstly, they use data produced by paleoclimatologists as parameters in their models. Secondly, they also need data to set up the boundary conditions of their models. Boundary conditions are parts of the Earth system that a model cannot change during a simulation. Different models and different models runs require different types of boundary conditions. Some of this information comes from other subfields of geology, such as data on topography. Other types of information are provided by paleoclimatologists. This could be, for example, the concentration of $CO_2$ in the atmosphere or, in models that do not have a fully represented ocean, sea-surface temperature. Furthermore, modellers need data to validate their models. Once they have finished setting the models up they run them and compare their output with data sets to check whether the model is producing reasonable results. If not, the models have to be adjusted.

[8] The name of my informants were changed to preserve their identities.

[9] I attended this summer school in 2011 and carried out participant observation.