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Managing Misunderstandings

The Role of Language in Interdisciplinary Scientific Collaboration

Marko Monteiro
Institute of Technological Research, Brazil
Elizabeth Keating
University of Texas at Austin

This article explores how scientists communicate with each other in interdisciplinary collaborative work. It is based on ethnographic research conducted with one such group, which is building a predictive computer model of heat transfer in prostate tissues. The analysis identifies strategies scientists use in their communication practices, including managing different understandings of the validity of knowledge, partial understandings among participants, and interpretive discipline crossing in group meetings. The ideas of productive misunderstandings and of registration as correlating distinct knowledge domains are used to interpret how scientists must manage their unshared backgrounds as part of the collaborative scientific work.

Keywords: *communication; interdisciplinary research; computer models; ethnography; cyberinfrastructures*

The practice of science is changing dramatically due to the increasingly interdisciplinary nature of research teams, where members do not share a common background (Hafernik, Messerschmitt, & Vandrick, 1997; Hey, 2001; Katz & Martin, 1997; Lieberman, 1986; Mountz, Miyares, Wright, & Bailey, 2003; Presser, 1980). Such collaborations become more relevant as the issues tackled by contemporary science often cannot be

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defined by one isolated discipline, relating also to funding mechanisms, career incentives, productivity, and increasing complexity of scale (Mauthner & Doucet, 2008; Wilson & Herndl, 2007). In this context, many resources are being invested in the attempt to integrate different knowledge domains in order to tackle problems differently; this includes information sciences and advanced computing applied to physics, chemistry, and medicine, what some are calling *cyberinfrastructures*. Funding agencies are increasingly pushing to promote interdisciplinary collaboration and the integration of cyberinfrastructures into knowledge building practices.

One area of special interest is medicine, where the push toward automation and integration of advanced computing is affecting both how knowledge is created and how interventions in the patient's body are conducted (Clarke, Shim, Mamo, Forsket, & Fishman, 2003; Lenoir, 2004). Cyberinfrastructures, which connect scientists and their objects with advanced computing infrastructures in order to build powerful models of physical and biological processes, are an emerging field for scientific practice and will potentially become an important concern for science studies scholars as well.

The role played by language in such endeavors has not been thoroughly investigated. In this article, our goal is to contribute to further understanding these issues by analyzing ethnographic data from one such collaboration: an interdisciplinary team engaged in building a computer model of bioheat transfer in the prostate for use in a new long-distance surgery protocol. Our specific focus is weekly teamwork meetings. At the meetings team members individually produce and present to others visual renderings of their part of the project, accomplishments, problems, and unmet challenges. During the meetings goals are defined, knowledge is shared, and new common perceptions of the problems at hand are developed. By looking at the misunderstandings that occur in the meetings, and how the scientists manage them in their work, a richer understanding of interdisciplinary collaboration can be accomplished.

Researchers of interdisciplinary teams (Baird, Moore, & Jagodzinski, 2000; Bracken, 2006) have identified several common problems that arise in such collaborations: differences in epistemology and method, different ways of formulating research questions, and differences in communication styles between members. Interdisciplinary collaboration can be risky (McCallin, 2006) in the sense that collaborators must discuss views about each other's work style, definitions, and procedures of establishing validity. As modeling projects multiply in medical and other fields, and the wish to automate and predict natural processes becomes more feasible and desirable, understanding the role of language in the development of such novel technological tools becomes increasingly important.

The following aspects of the role of language in collaborative interdisciplinary work will be discussed:

1. *Different understandings of the validity of knowledge:* While data objectivity is a common orientation in scientific work, different forms of evaluating it are used in our data. Some exchanges and misunderstandings occur as members describe or contest types of knowledge and validation procedures.
2. *Partial understandings:* the acceptance of partial understanding and the strategies used by collaborators to manage ambiguity and uncertainty are key to working with experts from different fields. Managing partial understandings, despite being cited as problematic in interviews, upon closer analysis can be said to be a source of emergent common understanding.
3. *Interpretive discipline-crossing:* Problems occur in meetings concerning overestimating or underestimating the expertise of others, including "what and how to see" and "what to hear." Members topicalize and manage interdisciplinary problems with verbal and visual representations and abstractions, for example, 2D, 3D, and 4D computer models, including temporal and predictive perspectives. The diversity of disciplinary representation practices makes translation and interpretation key aspects of meeting work.

We first discuss the ethnographic background of the study and then show examples from team meetings to illustrate interdisciplinary teamwork. We conclude with a discussion on the process of coordinating different bodies of expertise and correlating knowledge.

Disputing and Building Knowledge

Previous research on scientific work spanning the philosophy, history, sociology, and anthropology of science (Elias, 1982; Knorr-Cetina, 1981; Kuhn, 1970; Latour & Woolgar, 1986; Pickering, 1992; Rheinberger, 1992a, 1992b) has shown how the development of specialized sites of scientific work and how the influence of scientific practice changes over time (Daston & Galiston, 1990; Knorr-Cetina & Amann, 1990; Latour, 1990; Lynch, 1990; Lynch & Woolgar, 1990), as well as how the visual aspects of scientific practice are central to the process of "constructing knowledge" (Latour, 1995; Lynch, 2006; Pauwels, 2006). Scientific visualizations illustrate a particular discipline's analyses of an object's internal order and what are considered its essential qualities (Lynch & Woolgar, 1990).

Understanding the cultural context in which research is conducted is central to understanding technologies such as modeling life (and in this case also intervention) in a digital form (Helmreich, 1998). Such understanding also illuminates the limits and pitfalls of automating via computers activities such as diagnosis and surgical intervention, the role of cultural processes in the design of information systems in health practices, and the influence of the epistemologies of the scientists who build such systems (Forsythe, 1993, 1998). An important part of that cultural context is the communication strategies that enable collaborative work among the scientists. As the team members themselves acknowledge, the problem of communication is central to how the work is ultimately carried out. Their view is that this problem can be mitigated with mathematical formulations, as one scientist stated:

> So I think once we get past the communication part, then the mathematics and the other things are not as bad, I mean once we can write the equations, the boundary conditions and things on the board, everybody says ok, call it anything you want to, I understand what's going on. (Interview with Chris, Deputy Director of the institute that houses the project, engineer, and computer scientist)

Our goal in this article is to investigate the communication strategies central to the kind of collaborative work necessary to complete such complex tasks as the model under construction. The model depends on the collaboration of experts from a wide array of disciplines because of its specific aim to mathematically and visually model and predict how a laser will damage specific kinds of cells within the prostate (first in cell cultures and animal models, then in humans). This prediction is meant to be useful for clinical practice. The collaboration thus involves mathematics, computing, medicine, and biology, and effectively cannot be realized without the contributions from each field. A careful investigation of such communication practices thus provides an understanding not only of knowledge production practices, collaborative work, and shared construction of meaning, but may illuminate how language is crucial to the ongoing activities and success of such collaborations.

Interactions involving discovery and experimentation have been studied in anthropology, psychology, cognitive science, and communication. For example, among scholars interested in socialization and informal learning (Alač & Hutchins, 2004; Lave & Wenger, 1991; Ochs, Jacoby, & Gonzales, 1994, 1996; Schieffelin & Ochs, 1986) and social cognition (Vygostky, 1978; Wertsch, 1991). New affordances are created by new technologies through a process of challenge, question, and coherence building (Suchman, 1993). As previous ethnographic work has shown, new technology is not only a resource for representation, but in the process of organizing its use, people alter aspects of the communication system itself (Keating, 2000; Keating & Mirus, 2003). Seemingly mundane microlevel interactions, such as questions and explanations, build new shared conventions while cultural ideas retain fidelity over time (Keating, 2006; Sperber, 2000) in spite of adaptations to new conditions. New technologies for visualization are being developed, which have the potential to greatly enhance human perceptual systems and are shaping ways of doing and ways of thinking, communicating, and imagining (Hutchins, 1995; Vygostky, 1978).

Ethnographic Background

This article's findings derive from ethnographic observation of a group of scientists as they carried out their work.[1] This means that the everyday activities of the team were observed as they happened. In addition to this, team members were interviewed and videotaped. Our goal here was to achieve a close observation of communication practices as they happen on the ground, to then derive broader interpretations from these data. This allows for theory that takes into account the context in which these practices happen to try to come close to the scientists' point of view. The team we studied is located at a major public university in the southern United States. The team is working with data acquired at a research hospital in a different city 160 miles away, and makes use of a supercomputing facility belonging to the university to help process the data. The team is made up of professors, postdoctoral researchers, and graduate students. Their areas of expertise include computer science, biomedical and civil engineering, applied mathematics, computational mechanics, visualization, biomedical engineering, and medicine. Members of the team represent diverse national origins: India, China, Iran, Czech Republic, Poland, France, and the United States. Most team members are somewhat interdisciplinary in their educational background and have very complex research careers that span different disciplines and interests.

Ethnographic research was conducted between November 2006 and November 2007. This consisted of attending and videotaping the weekly team meetings, interviewing all active members of the team, and doing observations in the facilities where the team members work. Thirty-two meetings of the group were observed. Videotapes of these meetings were analyzed. All current members of the team were interviewed at least once.

Observations were made at two talks and one international conference attended by the team, and at the supercomputing facility. Two trips were made to the research hospital.

The team's work occurs mainly at the university. The institute that houses the project, founded by its principal investigator (PI), is where the meetings occur and where the visualization labs and some students' and professors' office spaces are located. The Department of Biomedical Engineering, located in another building within walking distance, is where the cell studies occur. The meetings are an essential component of the interdisciplinary collaboration. Work done elsewhere by individual team members, for example, in wet labs where prostate cells are cultured, on computers where the model is rendered, and at the research hospital, where data is acquired on the anatomy and temperature of body parts of interest to the model, is brought to the meetings. It is in the meetings that members are made aware of each other's efforts and where important aspects of the integration of the work are achieved.

The team's scientific goal is to produce a system that will enable accurate computer predictions of heat-induced cell damage to be computed and made available to doctors in real time. This technology will result in a new paradigm for minimally invasive thermal therapy for prostate cancer using lasers. The treatment is designed to reduce cost, time, and patient trauma. The ultimate goal is to use magnetic resonance thermal imaging (MRTI) to provide an operating room surgeon immediate feedback control over laser interstitial thermal therapy (LITT). Symptoms emitted from the cells of a living person will be used to immediately compute the effects of surgery, in order to make changes during the ongoing intervention based on an immediate, highly complex understanding of the effects of heat in the patient's cells. This entails trust in the authority and accuracy of a computer model to validate the results of surgery "before the patient ever leaves the table," as one doctor from the research hospital stated in an interview. An assumption is that this means ensuring a better and more cost-effective surgical outcome in cancer treatments.

The task is made complex due to its specific nature as a mechanical model of a phenomenon that occurs in living beings, that is, heat transfer in tissues, involving laser-tissue interaction, expression of heat-shock protein, blood flow in the area (perfusivity), among other variables that must be accounted for in the computer model. The hospital provides data in the form of magnetic resonance (MRI) images and temperature (MRTI) data in 3D, conducting experiments that support the computations done in the university.

The members of the team have diverse practices of scientific representation and modeling, for example, shared and unshared visual renderings of symbols and formulas, geometric renderings of tissue, and MRTI images. Practices and procedures for visualization (such as diagrams, graphs, tables, 3D images, and 4D representations of processes) are extensively used in the meetings. Formal presentations and conversational exchanges topicalize and contextualize problems in understanding how the visualizations *mean*, the validity of the relationships represented, and the acceptance of the procedure and results. Key activities include, for example, reading a specific mathematical function or reading a dip or shoulder in a graph, and correlating this understanding to a patient's body or to some physical process. The issue of understanding multidisciplinary representation and validation procedures is central to continuing the project on a day-to-day basis.

Communicative Event Structure

The meetings analyzed herein follow a recurrent sequential pattern, something that has been identified in other ethnographic literature (Kunda, 1992; Schwartzman, 1987). This structure makes possible certain types of participation while limiting others. Meetings are an important social form in American culture, a "type of gathering or encounter that is characterized by focused interaction" (Schwartzman, 1987). The importance of the sequentially produced nature of meaning in institutional interaction has been shown by researchers in conversation analysis and the analysis of talk in interaction (Drew & Heritage, 1993).

As other authors have discussed, the meeting structure provides a context where individual and group relationships, agreements, and disagreements can be framed and discussed (Schwartzman, 1987), and entail strategies of marking difference among members (Arber, 2007; Fasulo & Zucchermaglio, 2002; Jeffrey, 2003) based on expertise and competence. Yet meetings are also a place for the emergence of new patterns of understandings based on these differences. As a space where professional boundaries are negotiated (Arber, 2007), meetings relate each member's identity to the group as a professional/researcher. In the meetings members establish connections between their different subprojects in an interactive setting, and short-term goals and results are contextualized against project goals, standard acceptable knowledge, theories, and methods (Fasulo & Zucchermaglio, 2002).

The sequential nature of this knowledge acquisition process is organized over several one hour meetings. Each meeting is set aside for one team member to present her or his personal research results, methodologies, and current work, while the team has a chance to be informed, question methods and data, clarify misunderstandings, and suggest different approaches. In addition, it is through the sequential meeting process that this group identifies and establishes a common, "working" set of definitions, concepts, goals, and knowledge practices. While not all discussions in the meetings are conclusive in the sense that everyone understands fully everything that was presented, it is in the temporal sequence of each meeting that such understandings emerge and where longer-term goals are set.

The meetings take place in a conference room arranged with a series of parallel tables with five or six chairs at each one. In the front of the room there are two blackboards, and a screen that descends when the central multimedia console is turned on. There are also blackboards on the right side of the room (if one is facing the screen). The screen and the blackboards are a focus as presenters explain slides from their laptops, point to specific areas of the screen, or write formulas and other spontaneous visual representations on the blackboards.

The PI begins each team meeting by announcing the presenter, contextualizing their work, relating the presentation to previous and future meetings, and making brief announcements (e.g., visitors, travel, and grant applications). Goal-setting activities occur in the initial stages of the meeting and at the end of the meeting. The excerpt below illustrates the role of the meeting in goal setting as the scheduled presenter, John, a professor of mechanical engineering, begins his presentation of the work he has been doing.

Excerpt 1: Narrating Goals

1 John: Ok hum, well (.)[2] today uh Laura is going to uh (.3)
2 continue her talk, part two, but uh Dr. Mark wants, wants me to
3 say a few words, to see what we're doing, because we are k—,
4 we've been meeting every Friday (.) uh for some time just to
5 discuss uh, for th—, for the cell uh, cell (.) cell experiments.
6 And uh, let's review the *goal* of the project first. (.)
7 And uh, our goal of the project is to establish a real control
8 system to, to control the cell killing. That's basically, uh, the
9 short version our our goal. (.)
10 Now, this cartoon
11 ((*points to slide on screen*))
12 shows that, let's suppose this is the uh, the tumor. And this is
13 the the healthy region

((*slide shows tumor as a red circle inside a blue circle*)).
So we wanna *kill* everything, inside this tumor region and then
***protect* the healthy regions. Simply put that's the, that's our**
goal. The problem is (.) how much we are gonna kill this
((*points to red "tumor" area*)) (.)
and how much we are gonna, going to protect
((*points to blue on the screen*)).

The negotiation of how to describe goals and problems is key to collaborative work. In this excerpt, John describes it as "killing" the tumor cells and "protecting" the healthy ones. He uses a visualization where these regions are clearly marked in different colors, a distinction that is much harder to ascertain when looking at the actual data. His goals are also described in terms that are broader than the model-building activity itself. He refers to the actual surgery, where a doctor will be trying to eliminate a tumor aided by model predictions. Contextualizing the collaboration in terms of a surgery helps scientists to see beyond their individual disciplines and grasp the problem in a more holistic fashion. In interview, scientists also described how participating in a project that involves medical applications serves as an incentive, in terms of helping people, saving lives, and promoting health.

In the next sections, we discuss how different knowledge concepts are concurrently used in meetings, how partial understanding is acknowledged and managed in their interactions, and how scientists engage in interpretive discipline crossing as part of their communication work.

Analysis: Managing Misunderstandings

Different Understandings of the Validity of Knowledge

Team members in the meetings manage different ideas about the nature of knowledge, how it is obtained, and how it can be tested or confirmed. One such form, very common in the meetings, is the "eyeball norm." The "eyeball norm" denotes a form of knowing that relies on pattern recognition and secondary calibration of ways of representing cause and effect. It is a good example of how scientists must rely not only on their discipline's methods for establishing validity, but also on practical evaluations of how adequate a set of data looks, based on its rendering as a graph or a 3D visualization. The fact that experts from more than one discipline mention using the eyeball norm, both in interviews and during the meeting, also suggests that interdisciplinary collaboration relies on such strategies to mitigate lack of shared norms for objectivity.

> So there are different norms, one is just subtract, this is one kind of norm. One is a kind of least squares norm, they have things like that. **So eyeball norm is a kind of a norm that's you just say from your eye it's good or bad.** (Interview with Clark, PhD student in computer science)

Such norms used by the participants are based on particular relationships which are learned over time. If the data looks right (based on experience or right enough measures), this can be a preferred strategy in some instances. Errors can be detected using the eyeball norm and can be later tested out mathematically or in cell studies, and they may also incite a call to the hospital in order to obtain data that contain less noise.

Another knowledge strategy discussed is *intuition*. Intuition and its role in interdisciplinary work were described in a conversation between Lewis, the project PI, and one of his graduate students in computational and applied mathematics, Lynn, before the meeting started:

Excerpt 2: Intuition as a Measure of Validity

1 Lewis:	You know
2	((*coughs*)),
3	they say that uh(.3) math—mathematics is intuition. (.2)
4	But it's really not. (.4)
5	Prior to intuition you have to have, precision. (.2)
6 Lynn:	[I thought physics was intuition].
7 Lewis:	[On a certain level ((*raises one hand indicating high vs. low*
8	*levels*))] it's intuition.
9 Lynn:	I thought physics was intuition. (.2)
10	he he (.)
11 Lewis:	(?) mathematics is too.

Here intuition is described as sequential, after precision and training. This means that, while intuition has a place in mathematics, it does not substitute usual measures of mathematic validity such as precision. In fact, it derives from extensive training in mathematics. The value placed on mathematical methods is both an expression of the specific kind of work being conducted (mathematical modeling as a way to achieve prediction) and a way to mitigate unshared knowledge practices and methods. Thus, intuition here refers mostly to embodied expertise as an expression of extensive knowledge of how mathematical relationships express natural phenomena, which can then inform the scientist as he looks at a graph. For example, in the sequence below, Luke, a PhD student in computational and applied mathematics, is asked about his *physical intuition* by Mark, Professor and Chair in Engineering, as a way to help interpret a 3D rendering of results:

Excerpt 3: Physical Intuitions

Mark: You have a physical, intuition why, the mountains have uh two
hills and etcetera?=
Luke: =I have
Mark: Because (?) that is X is because is, uh: you are saying this, is a
minimization with respect to the (.) (XZ) or XY.=
Luke: =The [the]
Mark: [so] it has to have a some, [?]
Luke: [I a—I attribu—I attribute]
I attribute the maximums to noise. I mean so, if you just look at,
look at, hum
((*walks to screen and points to the graph*)),
this dip in temperature value, I mean this is being integrated,
hum over over space.

Intuition can be a stand-in idea for expertise in judging results and procedures that are difficult to share with nonexperts. There is a significant amount of trust involved, as the expert is asked to correlate the appearance of the graph with a physical phenomenon. The trust refers to the student's capacity to correctly infer which mathematical expression best correlates with a phenomenon of interest, based on its numerical results. While not all members are experts in establishing these relationships, the work of convincing the other members depends heavily on the way the results are visualized and on the explaining of that correlation in physical terms (and not solely as a graph). By asking about the physical intuition, thus, Mark tries to derive an understanding of a physical process of interest beyond the correctness of the results of a formula. This in turn helps other members to engage with the discussion beyond the specificities of the formulas.

Partial Understandings

Developing tools for managing partial knowledge of what is being presented in any particular meeting is a crucial element of the work of collaborating across disciplines (Wilson & Herndl, 2007). The team is composed of experts from different fields, who "may have little common background" (as described by one of the team members) and must make sense of information presented in diverse ways. It is a team where each individual "knows something about some of the parts of the project, and must develop some working knowledge of the other related parts" (Interview with Mark). The difficulties of this task, including measuring the success of the development of "working knowledge" was described as follows: "It's always difficult to speak to people with whom you have little common background" (Interview with Ken, Professor and Chair, Computer Science).

Doing cross-disciplinary work entails developing some measure of a common vocabulary, understandable visualizations and definitions, analogies, and targeted explanations. Improving or maximizing the potential for understanding of a message is no easy task, and message structure can affect such understanding (Yaros, 2006), which does not occur from mere attention to a certain message. As one of the team members described in an interview:

> We need to have a **common set of words that we all use to mean the same thing**, because what you find out is . . . if you listen to someone from computer science, you think you might know what he is saying, or Dr. Carl will start talking about meshing, **and the words that he is using are not quite the same ones that you use**, or I'll try to interpret, and figure **a common set of definitions** on what everything means. (Interview with Chris)

Such a common set of words, as became clear in the ethnographic research, does not fully materialize in the meetings. Rather, understanding is reached through negotiating meaning during the presentations and conversations that happen in the meetings. This negotiation involves interpreting visualizations, using the blackboard to complement meaning not clear from the presentations, questioning methodology and definitions, and trusting in the expertise of peers when they cannot grasp fully the concepts at hand, outside of one's "domain":

> So sometimes it was hard to understand because they were out of the domain, out of our domains. But I guess it's a good idea actually to . . . Because I think that **the goal is not to completely understand what they did**, but one tries to try to understand what they did, because at least it gets us more and more familiar and, to what they're working with, and maybe . . . during the presentation **we can extract some idea of them**, which would have our work, or which would have their work, if that's a possibility, and even if after the presentations, you can do this once, then it's great. (Interview with Clark)

Members realize they must rely on each other and skillfully manage partial states of knowledge. And as Clark suggests, there is a lot of learning involved in these meetings. The goal, as they acknowledge, is not to bring everyone to the same level of expertise on all topics, but to arrive at a working set of understandings that allow the team to work together and the project goals to be reached. Many in the group feel that this sort of experience adds greatly to their own expertise when they have a chance to be exposed to different knowledge domains through highly respected experts in their fields.

Developing partial and full expertise, as well as correcting and complementing understanding problems with the preprepared slides is thus a constant feature of each meeting. The team does this through a series of strategies including using the blackboard to complement their preprepared slides. Such ad hoc visualizations may include mathematical formulas, simplified graphs, schematic drawings, and other shapes that aid in the explanation of their topic. As has been noted elsewhere, the use of visuals may aid in focusing attention to helpful information, providing a context for the building of internal connections (Mayer, 1989; Mayer, Bove, Bryman, Mars, & Tapangco, 1996). In the next excerpt we see Lewis, the project PI, having trouble understanding what Luke, his PhD student, meant in one of his slides:

Excerpt 4: How to Manage Partial Knowledge

Lewis: Is the power fixed?
(.)
Luke: Power is fixed. [So what I wann—]
Lewis: [All you're moving] is the position?
Luke: Yea, I just I just needed, I just wanted a small parameter space
so that, I could just hum
((*points to formula on blackboard*))
plot this objective function.
Lewis: Ok.
Luke: See what's happening?=
Lewis: **=you just have to tell us what you are doing**, that's all, **and**
usually you have to do it in writing because we can't hear
(everything).

Doing it in writing often refers to writing out a formula that explains a concept being discussed. Especially with those team members more expert in mathematics, understanding of results and methods is only fully accomplished when the presenter explains through mathematical relationships the ideas present in his or her slides. In almost all the meetings, in addition, writing out formulas on the blackboard is a necessity to complement those formulations present in the preprepared slides, by request from other team members.

Questions make explicit the different levels of knowledge and confidence one has in different bodies of expertise. In the next excerpt we see Carl, Professor and Chair, Scientific Visualization, ask Laura, a PhD student in biomedical engineering, about her cell studies:

Excerpt 5: Question From a Partial Expert to an Expert

1	Carl:	So you're using a, flow cytometer fo:r the left
2		((*referring to picture on the left of the screen*))
3		(.) the scattering study.
4	Laura:	Yes.
5	Carl:	And you're using a::
6	Laura:	a (?) flow cytometer.
7	Carl:	With these hum, markers, the io pro and the PI markers. **And how**
8		**reliable are, these measurements?**
9		(.3)
10	Laura:	As far [as the machine goes?]
11	Carl:	[do they, I mean you're]
12		using this machine, which has some [software errors].
13	Laura:	[machine itself] is very re—
14		reliable.=

A question about the data acquisition process of the flow cytometer shows how, while one member (Laura) is fully confident in her instruments, the other member (Carl) is working to assess the experiment through the usual methods used in his field. The instrument in question is commonly used in the type of experiment Laura is doing, namely, *in vitro* cell cultures that will be used in validating the model through heating experiments. While she presented data concerning numbers of live or dead cells accepting the flow cytometer's reliability, many members had questions concerning this methodology and the physics of how the instrument worked. The excerpt below follows from the previous exchange between Laura and Carl:

Excerpt 6: Defining Uncertainty

1 Carl: how close is that to: being positive, are you at a—(.)
2 **what is the::, uncertainty, in [that]?**
3 Laura: [S—] So (.)
4 usually what is done in literature, what what wh—, almost, all o—,
5 not everybody but, majority of people do is
6 (.) they just uh draw a line, like what I do—did there (.)
7 they just make hum, region. They mark a region and say, anything
8 beyond this is positive, anything below this is negative. (.)
9 **That's what usually people do.** (.2)
10 But uh, there are softwares that do uh, clustering (.)
11 cluster analysis on these datas, a:nd, uh:, I'm planning to use uh
12 hopefully one of those softwares. (.)
13 As opposed to just uh marking some region. (.)
14 But yes, there is some uncertainty associated with each uh data
15 analysis.

Carl and Laura engage in a process of mutual orientation, including orientation toward consensus in her discipline about how such instruments are applied and the results used. Laura explains that her method for dealing with uncertainty is by classifying the data at hand in a particular way that is usually what people do. Namely, she interpretively defines areas in the dot plot that most probably refer to the different categories of interest, allowing a measure of uncertainty. This definition of *alive, dead*, or *apoptotic* cells is problematic to the computer scientist, as he demonstrates below:

Excerpt 7: Discipline-Specific Assumptions

1 Laura: (?)But yes, there is some uncertainty associated with each uh data
2 analysis.
3 (.2)
4 [We try]
5 Carl: **[For a person who] is coming outside this field, I mean, I would**
6 ***assume* that you cannot partition the data, into: these categories**
7 **based on values. You must have a category which is called**
8 ***uncertain,* I cannot decide**. (.2)
9 So I—in this, what I'm hearing is that, all of the data gets
10 partitioned into either a live cell, a dead cell or an apoptotic
11 cell. (.)
12 And I think there should be a fourth category. (.2)
13 *Undecidable.*

While for her individual objectives Laura was confident in drawing a line separating live cells, dead cells, and debris according to where the dots lay in the plot, her confidence was not initially shared by the others. In this excerpt, we see Carl proposing a fourth category (undecidable) to complement Laura's analysis. By doing this he reveals not only his partial understanding of the dot plot methodology, but suggests ways to analyze the results that are more in line with what he considers objective. To achieve this all elements had to be categorized (including those uncertain ones), while for Laura's goals, that fourth category was not a necessity.

Interpretive Discipline Crossing

The diversity of disciplinary representation and categorization practices makes translation and interpretation key events themselves. In the following excerpt, team members together analyze an image in the form of a 3D graph. They are collectively attempting to translate properties of the visualization, a rendering of temperature data from the MRTI images. Mark asks a question about the relationship between the abstract visualization and the human body or where the surgeon will aim the laser to destroy cancerous cells. He is questioning the correlation between the graph shown and the physical process at stake, and he calls this the physical meaning. He is corrected by Lewis on his understanding of the relationship between visualized changes in slope, or the graph's hill and valley, which turns out to be opposite of the meaning intended by Luke, who made the graph.

Excerpt 8: How to Read graphs?

Mark: (?), but anyways. My (?) it is a combination of
things, one is a physical (.) *meaning* of it, because
the question is now, you are saying where where where
the hill is (.) I will will put the laser, I will not put the
laser. So it has to be intuitively (h) (?), where the optimal
laser is, should [?]
Lewis: [No it's] in that little valley, it's not on a
hill.

In the sequence, Ken provides a retranslation of what the graph means, adding to Mark's interpretation and helping to clarify the visual to himself and the group. His characterization is affirmed as correct by Luke, the presenter:

Excerpt 9: What He Is Trying to Do?

Mark: (Well what about it), it should (?) be somewhere, so
intuitive (h) intu—also where they also ↑peak
[(?) intuitive reasoning].
Ken: [What, what he's—]
What he's trying to do is to minimi:ze (.4)
find a—a place, if I understand properly that
minimizes the difference between what the MT—MRTI:,
shows, and what your model shows.
Luke: Yes
Ken: A—a choice of parameters for that.
(.)
Luke: Yes.

Minimize here is used to refer to the important process of reducing the difference between what the model predicted and what the data collected shows. The team members are working to achieve understanding across many representational systems, not only the data on cell temperature change but also on a new predictive model. Noise acquired in signal processing or computing of data without salient meaning produced should be excluded from this interpretive process. Likewise, the scientists many times had trouble understanding exactly the data being presented in the complex visuals available at the meetings. The 3D renderings referred to anatomical data, temperature data in the prostate, or 3D renderings of a mathematical function.

This is the case in the two last excerpts, where the scientists are trying to correlate the 3D features presented in the image (valleys and hills) with mathematical functions, which will help them explain or represent in mathematical terms the biological phenomena of interest. This very complex conceptual move is aided by the visualizations of formulas. Yet many times the visualizations can be themselves sources of confusion or misunderstanding. In spite of this, new common understandings emerge from the exchanges aimed at managing and solving such confusions.

As our data show, assumptions inherent in a picture or graph, in contrast to claims made by other studies (Jeffrey, 2003), can sometimes create confusion instead of simplifying the apprehension of data. Discipline-specific and even cultural conventions of color use (e.g., relating to differences in temperature, a variable that is important to the project) and high and low scales, for example, can influence how visual data are interpreted in the meetings. In the following excerpt, Carl is concerned with a color-coded representation in red and blue contrasts that he mistakenly reads as temperature change:

Excerpt 10: How Does Color Mean?

Luke: (?) and I do know that this minimum ((*points to*
screen)) is, approximately where, th—the, the
contours, are th—the the the temperature is highest,
so that's, roughly where it's at. (.)
And hum (.)
Carl: But in in that, that's not where the temperature is
higher? **Then, temperature colored by:, red being**
higher than blue?
(.)
John: **No he's not plotting temperature, it's the**
(objective)=
Carl: **=oh the devi—deviation** (?)

Confusion arising from the interpretation of visualizations reveals at the same time the specific premises the different disciplines have concerning what counts as objective data (as in the flow cytometer example) and some of the problems in collaborating in complex problem solving across disciplines. If conventions for visualizing the results of a mathematical function are not shared, as in the example earlier, other aspects of the project (e.g., the fact that it deals with heating of cells) can be used by the scientists as reference and lead to erroneous interpretations. Questions that emerge from such interpretations are crucial, however, in the weekly process of working through data to develop common understandings of the problems at hand. As such, these can be termed *productive misunderstandings*, as a way to stress both a lack of shared knowledge inherent in many communication processes in these scientific collaborations and the role these misunderstandings play in enabling the progress of the collaboration itself.

Conclusion: Registration as Metaphor for Knowledge Building

In this article we have focused on a team building a computer model for use in a new cancer surgery protocol in order to better understand how cross-disciplinary teams manage misunderstanding and the work of team members outside their disciplines and knowledge domains. By focusing on weekly team meetings that enable the production of shared understandings, we identified some ways team members negotiate different understandings and measures of the validity of knowledge. The management of partial understandings, strategies to manage ambiguity, and the role of language in discipline crossing are all important elements in the production and interpretation of visual, gestural, oral, or written information in this collaborative interdisciplinary team.

We have analyzed the practices discussed earlier that are part of everyday interdisciplinary innovation and sense making in collaborative modeling work. Our aim is to understand scientific collaborative work and gain insight into processes of contemporary knowledge making, which are increasingly attempting to define biological processes in predictive computational terms. In order to better understand the complex processes involved, we feel the concept of registration used in scientific imaging research (and a crucial part of the project under analysis here) may be a productive way to think about how these interactants convey to others their cognitive work in this process of interdisciplinary collaboration. Registration entails the idea of making two representations match, and is described by one of the team members as follows:

> So we have to kind of match the two images, so that we know . . . what part of the prostate in figure 1 corresponds to what part of the prostate in figure 2. . . . Basically it means that, if in figure 1 we have a prostate, then we should know in figure 2 that how much it is translated from figure 1 or how much it is rotated from figure 1. **We have to kind of match, superimpose one figure onto another properly**. (Interview with Clark)

Images of the same prostate taken in different times need to be made comparable so that they can be worked on. In a similar fashion, different skills, concepts, visual representations, and so forth produced by team members from different backgrounds, disciplines, and stages of their career emerge in weekly meetings and must be interpretable from different perspectives. The process of improving knowledge registration occurs through communication, translation, contextualization, managing, and establishing different sets of definitions and partial understandings.

Registration as a metaphor here seeks to describe the constant task performed by the team to correlate their different knowledge domains into common understandings that can be usefully worked into the common goal of reaching the final computer model of heat transfer in prostate tissue. Some of the more crucial knowledge domains involved in this project are biology, mathematics, engineering, and computer science. While full registration or a perfect correlation between all of the concepts involved here is very hard to attain (if not impossible), the process itself is crucial to the progress of the collaboration. The idea of productive misunderstandings, as a way to interpret these processes, seeks to indicate how the mismatch and partial understandings that are a part of communication events in the meetings are more than miscommunication: They are rather productive sites for the identification of erroneous interpretations, illumination of unshared premises (which can then be mitigated) and development of shared understandings of what the common goals of the project are.

Some of the challenges in presenting results from a biological study to an audience of engineers, mathematicians, and computer scientists, for example, involve unshared premises that range from how to present data to how these disciplines evaluate what can be considered valid results. Likewise, trying to explain what a scientific visualization means involves, beyond the simplifications it enables, paying attention to how other scientists will interpret color, shapes, or how a formula written on the blackboard will make it more understandable. This means that, for interdisciplinary collaborations, instead of "getting past the communication part," as one scientists here suggested, we need to look further and explore what the challenges of communicating across disciplines can mean for the growing number of such projects that are being undertaken.

The project of automating surgical procedures and predicting surgical outcomes is still in its infancy, and many of the problems identified in our data will most likely play a role in other such initiatives. In terms of interdisciplinary collaborations more broadly, the problem of communication, as the scientists in the project we observed suggest, is more than simple confusion, easily fixed by better images or explanations that are clearer. It goes to the core of the kind of collaboration enacted by this and other such groups, which are redefining the way we understand scientific problems and the very boundaries of traditional scientific disciplines.

Notes

1. This ethnographic study was approved by the University of Texas at Austin's Institutional Review Board, having met all requirements for the ethical study of human subjects (UT IRB Study No. 2006-11-0040). All names have been substituted for by pseudonyms to protect the privacy of the scientists.

2. List of transcript conventions:

[	point of overlap onset;
]	point at which overlap terminates;
=	latched utterance;
(0.0)	lapsed times in tenths of a second;
,	comma indicates a gap between utterances too short to time, more likely a very short pause;
(.)	a gap of approximately one tenth of a second;
word	italics indicates speaker emphasis;

↑↓ marked shifts in higher or lower pitch in utterance immediately following arrow;
! animated and emphatic tone;
? rising intonation, not necessarily a question;
: prolongation of immediately prior sound;
:: the more colons the longer the sound is drawn out;
— cut off of prior word or sound;
. full stop, stopping fall in tone, not necessarily end of sentence;
(?) unintelligible;
(h) indicates an in breath;
w(h)ord: breathiness as in laughter, crying;
heh heh: laughter particles
(word) dubious hearing
(( )) transcriber's descriptions rather than or in addition to transcriptions.

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Marko Monteiro is an associated researcher with the Institute of Technological Research (São Paulo, Brazil), having recently worked as postdoctoral researcher at the STS Program, the University of Texas at Austin. His research concerns representation practices in science and society, including ideals of masculinity in Brazilian men's magazines, biotechnology asmolecular representation, and visual representation in science.

Elizabeth Keating is professor of anthropology at the University of Texas at Austin. Her research concerns the impacts of technology on society, particularly the role of technology in shaping communication. This includes the role of language and other semiotic systems in building and maintaining social hierarchies, multimodal communication, and sign language.