The effect of disciplinary identity on interdisciplinary learning during scientific group meetings

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Abstract: Learning to become an interdisciplinary scientist will be needed in order to participate in the scientific research of the future. It is therefore of great importance to learn about the challenges graduate students, with various disciplinary backgrounds, face when carrying out interdisciplinary scientific research. We used the weekly group meetings of an interdisciplinary research group, in the field of systems biology, as a platform to probe the challenges to learning interdisciplinary science. Group meetings were observed and interviews were carried out with the group members. A visible, if sometimes subtle, difference between the challenges facing biologists and those facing physicists was identified. Physicists encountered difficulties in grasping the biological knowledge organization; while biologists found the models suggested by physicists over simplistic. The views of the group members on the nature of the disciplines of physics and biology complement our understanding of the possible causes of some of the identified challenges.

Introduction

Contemporary scientific research is becoming increasingly more interdisciplinary in nature. Innovations are moving beyond disciplinary borders while funding agencies are also promoting interdisciplinary studies (Kafatos & Eisner 2004; Sung et al. 2003). Thus, new interdisciplinary fields of study emerged in the recent years. For example, bioinformatics, which combines elements from biology and computer science (Luscombe et al. 2001), and systems biology which combines approaches from biology, computer science, engineering and physics (Aderem 2005; Allen & Cowley 2004), and which has its paradigmatic roots in systems thinking (Gutierrez et al. 2005). Thus, learning to become an interdisciplinary scientist will be needed in order to fully participate in the scientific research of the future (Bialek & Botstein 2004). However, most scientists in training today are not involved in an undergraduate curricula that prepare them to think like interdisciplinary researchers (Bialek & Botstein 2004; Gross 2004). Most postsecondary studies are disciplinary in nature, and students who wish to carry out interdisciplinary research face significant cultural barriers such as differences in the scientific language used, the approaches to scientific research, epistemologies, learning styles, teaching styles and disciplinary discourses (Ares 2004; Bradbeer 1999; Sung et al. 2003).

There are two possible ways for developing an interdisciplinary scientist: either the scientist can become proficient in one discipline and then cross a disciplinary border to another field, as is often the case today, or he can study an interdisciplinary curriculum in an earlier stage of his scientific career (National Research Council [NRC] 2003). Until interdisciplinary curricula will become widespread in undergraduate education, most graduate students who wish to become interdisciplinary scientists face several challenges, including mastering disciplinary knowledge and language to a level that will permit them to contribute to different disciplines as well as reconciling conflicting methodologies, epistemologies and paradigms (Golde & Gallagher 1999). It is therefore of great importance to learn about the challenges graduate students, with various disciplinary backgrounds, face when carrying out interdisciplinary scientific research in the course of their studies.

Learning science at the graduate level is not limited to formal course work. An important part of such learning occurs during the daily scientific work. This learning is mainly a result of talking, reading and engaging in the different aspects of the process of scientific research. Not only is such learning inseparable from doing the actual research, but also individual learning is inseparable from the collective learning that takes place in a typical research group. Such learning usually occurs by undergoing enculturation into a practicing community of scientists. Communities of practice provide the setting for the social interactions needed to engage in a dialogue with others and to see diverse perspectives on any issue (Brown 1994; Lave & Wegner 1991). In a scientific research community of practice, many of the interactions between members have an intrinsic learning aspect. Some of the learning that occurs within this community is therefore cooperative or collaborative in nature.

Group meetings of scientific research groups were previously reported to be central for the generation of ideas and conceptual change of group members (Dunbar 1997). The group meetings are not only an environment for advancing scientific research but also an important learning environment. In this learning environment every group member, in turn, teaches the other group members about his research and is challenged by them when they disagree with or misunderstand him. Each participant teaches what he knows best - his own research. Moreover, participation in group meetings was shown to be effective in assuring immersion into the culture, language, technology and literature of the scientific disciplines involved in interdisciplinary research (Sung et al. 2003).

Explaining to someone else is considered a highly effective form of elaboration (Webb 1989). Students who engage in elaborated explanations to others, were found to gain the most from cooperative learning activities (Webb 1989). This may be explained in part by the process which the person who delivers an elaborated explanation undergoes. This process involves clarification and reorganization of the material to oneself which allows for the discovery of gaps and discrepancies in ones knowledge. It may also include formulating the explanations in more than one way, generating new examples, linking the examples to the students' prior knowledge, and using several visual representations. All of these are likely to expand and solidify the understanding of the material for the one giving the explanation (Webb 1989). Although most studies on cooperative learning were conducted on the primary and secondary educational levels, graduate students also found cooperative learning useful in increasing both conceptual understanding and interpersonal and communication skills (Towns & Grant 1997).

So far, most of the studies that examined learning in research laboratories focused on scientists and scientific groups with a well defined disciplinary identity. Some studies concentrated on developmental biology laboratories or laboratories working with pathogens (Dunbar 1995), others on molecular biology laboratories (Amann & Knorr-Cetina 1989; Latour & Woolgar 1986), and yet others on high energy physics laboratories (Traweek 1988). In this study we examined the weekly group meetings of an interdisciplinary scientific research group as a platform to probe the challenges to science learning of the group members. We focused on events that occurred during group meetings since, as mentioned above, group meetings were found to be central to the intellectual life of scientific groups (Dunbar 1997). In addition, participation in group meetings was proven to be effective in assuring immersion in the culture, language, technology and literature of the scientific disciplines involved in interdisciplinary research (Sung et al. 2003). The group members' views on the nature of the disciplines of physics and biology and how they influence their learning of new disciplines were also examined.

Objectives of this study

i) To characterize the challenges to science learning during interdisciplinary scientific research group meetings
ii) To characterize the views of the research group members on the nature of physics and biology, and how those views influence learning of a new discipline.

Methodology

Subjects

The subjects of the research were members of an interdisciplinary scientific research group which is a leader in the field of systems biology, in an academic research institute. Systems biology, as practiced by this research group, focuses on investigating biological systems from a physical perspective, thus this group's research is aimed at finding basic systemic principles underlying biology. The group includes biologists, physicists, and bioinformaticians. This research group was selected on the basis of the quality of the group's publications, the significance of their already achieved discoveries and the type of research they conduct (following Dunbar 1995). The group consisted of 20 members during the course of this research.

Methodological approach

The research method used here is a qualitative-constructivist approach based on a thematic analysis (Shkedi 2005). Interviews were used as the primary sources of information and direct observations of group meetings as secondary sources of information (Shkedi 2005). Two research instruments were used during the interviews: a list of 53 questions and a collection of written episodes transcribed from the audio-records of the observed group meetings. Episodes were taken from both group meetings where the interviewee was the speaker and from other group meetings. The episodes were used during the interviews as a tool for promoting reflection.

Group meetings were held weekly. In each weekly group meeting, one or two group members presented their research and asked for feedback and suggestions. The research presentation included the theoretical and practical background of the research presented, the model and/or the experiments that were carried out, the results and when possible the conclusions. The group members could intervene at any time to ask questions or to comment. Often discussions deviated from the intended plan of the lecture. The group leader was active in both initiating and participating in the group discussions, often moving to the front of the room to draw on the blackboard. The meetings were audio-recorded.

Fourteen interviews were audio-recorded and analyzed. Each interviewee (75 to 90 minutes) was interviewed once. The interviews with the group members took place one week to one month following the presentation of their research in a group meeting. The interviews were semi-structured and in-depth (Shkedi, 2005). Conversations were prompted by leading questions and presentations of episodes from the group meetings, and were open in nature.

Method of analysis

The recordings of the interviews were transcribed. The transcripts were segmented and analyzed using the Narralizer™ software (Shkedi & Shkedi 2005). The analysis included four stages, as recommended by Shkedi (2005): '*The initial stage of analysis*' '*The mapping stage of analysis'*, '*The focusing stage of analysis'* and '*The theoretical stage of analysis'*. In each step a categorical tree was built and subsequently expanded or refined. A meaningful extent of validity was reached by triangulation between observations in group meetings, interviews and the published literature. The group members were allowed to view and comment on all the quotes used in this study. A meaningful extent of reliability was reached by inter-rater reliability checks for the first two stages of the analysis. The episodes were inserted into the mapping tree by another researcher using a written description. The researchers met several times in order to refine the description and agree on the coding. The level of match was compared for the first 35 episodes out of total 62 episodes. These 35 episodes were inserted into 47 categories by the fellow researcher. Forty four of these insertions were matched by the primary researcher leading to a percent match of 93.6%.

Results

Interdisciplinary challenges to learning during group meetings

Two interdisciplinary challenges were encountered while the group members presented in their group meetings. The first challenge is that the presenter should not assume that all the listeners share the same background knowledge. The second challenge is that a presentation that can be understood by everybody may not elicit an effective input to the presenter. Thus, a presenter is often torn between two conflicting forces: on the one hand, the desire that all group members understand his presentation and on the other hand, the need to receive meaningful feedback and criticism from the group members. Even veteran members are not sure where such a balance can be found, as described by one of the veteran physicists:

> Take for example the meeting I gave last week, I started building it in a way that [the biologists] could understand, but we ran into the problem of too much diversity. If I will start with a first lesson about dynamical systems, then the physicists in the group will go to sleep. Ultimately, the people from whom I expect feedback and smart insights on dynamical systems are the people who already dealt with dynamical systems in the past. People that see stuff for the first time, often have good ideas but also often not. It is hard, this heterogeneity, it is problematic. The result is that things are often either above your head or not interesting.

The group leader is aware of the challenges related to presenting to such a highly diverse audience and he requires the presenters in group meetings to be very clear, often intervening in the presentations in order to clarify certain points. A group member described this:

> Often when someone got a little lost in building the presentation or communicating it, [the group leader] focuses things, shows the correct logical order, what's the main question, what's the basic approach and what are the significant results. Then everything fits in a much more logical format. I feel the contribution not only in the specific content, whether I understood something or not but also the presentation method. It really helps to understand how and on what to put emphasis and what is the best logical order to do that.

When presented with the idea that the reason for the group leader emphasis on clear and well delivered presentations is the result of the field of systems biology being interdisciplinary, most members agreed that presenting to an audience composed of both biologists and physicists requires extra clarity and that this may be the reason for the emphasis given by the group leader on the quality of the presentation. As one member said:

> I think that because [the group leader] lives in several different worlds, it is very clear to him that you must know how to direct the presentation or how to create a presentation which has some universal base that is relevant to all the groups or to as many groups as possible from the groups composing the audience. This is why it is so much in the foreground of his awareness. It is very probable that if we were dealing with lets say, quantum optics and gave lectures to the same community – quantum optics people, then the whole thing wouldn't have been so important.

In addition to the aforementioned challenges, there was a visible, if sometimes subtle, difference between the challenges facing biologists and those facing physicists, as described below.

Challenges facing physicists in the group

The knowledge structures of different disciplines often vary (Becher 1989). This may explain why physicists in the group reported that it is difficult for them to construct their biological knowledge in a way that reflects the knowledge organization of the discipline. The physicists said that they often see biology as full of details and that it is hard for them to locate the central details and to find a guiding logic. Possibly this challenge is related to the structure of knowledge in biology in general. A relatively new physicist in the group felt that he could not really see beyond the details of biology. Biology is presented to him, especially in text books, as a mass of data without organization. He was deeply frustrated by this saying:

> I will never be as good as the biologists with quantities of data [..]. I think that I'll have a problem that I will insist on understanding everything to the depth before I go to cover the breadth. I really have a problem reading [biology textbooks]. I really get upset I read things and I don't understand what is it they want to say.

Another physicist had similar opinions about biology being full of details. He added that dealing with many details is an expertise of biologists, not physicists saying:

> There are many things that biologists can do better than physicists, all this thinking in terms of pathways. That A activates B that inhibits C that facilitates…
> Q. What do you find difficult here as a physicist?
> First of all you need a good memory, all this dealing with details doesn't come naturally to physicists really. But what can you do, there are lots of details in biology and what can you do, there are systems in which all these details are important.

The first member quoted above felt that it was something in his understanding that was lacking while the second member believed that it is possible that all the biological details are important. The latter feeling may hint at a difficulty with organizing the knowledge in a meaningful way which will allow separation between what is important from what is less important. The group leader, a physicist with a lot of experience in biology, reflected on learning biology saying:

> It is difficult to enter biology[..] There is a period when nothing is understood. Even when I sit in a biological lecture it is difficult to listen to the lecture if there is no clear idea that unifies all the facts.

It seems that even when a form of knowledge organization is presented, physicists in the group often find this form of organization somewhat confusing. A group member described this as a different way of thinking that biologists have. He dubbed it 'epistatic thinking' saying:

> My association for biological thinking is 'epistatic thinking'. I go to a biological lecture and the lecturer starts to make a chain where gene X affects something and represses gene Y and then gene Z does something and something more and the chain becomes longer. But I already lost the chain of thoughts after two stages because I don't have 'epistatic thinking'. The biologists next to me understand this very easily.

Biological systems are not only complex but also unique (Mayr 1988). The physicists noted their reluctance in learning about biological data that is a result of its high specificity to particular systems, making it nontransferable to other systems. One physicist referred to the issue of specificity saying:

> The problem with all this information is that it is information on a specific gene. Now, if you move to another system, then all these pieces of information on what gene interacts with what gene becomes irrelevant. In Physics [..] knowledge is more modular, you can transfer it from one system to the other.

Biological knowledge is extensive, complex and interconnected at many different levels (Fisher et al. 2000). In biology, however, the level of interconnectivity might make a lack of conceptual knowledge and familiarity an interference with further learning for the physicists. Due to the high degree of connectivity in the structure of knowledge in biology, it is difficult to learn new things in biology without having enough prior knowledge to link to the new knowledge. The difficulty is not only with understanding the structure of biological knowledge, but also with a lack of specific knowledge in biology. A physicist described how his lack of familiarity with the details of a system decreased his gains from biological lectures. He said that:

> In systems I am more familiar with, I already know the names of 10 or 15 genes so that when I hear the name of a gene, I already have some association related to it. From a physical point of view, you are trying to make generalizations, not to give too much emphasis to a specific gene or gene name but to think on more general effects and what happens system-wise. [..] Someone who knows all the details and knows what everything is supposed to do, when he hears a gene's name he has all the associations from all the interactions he knows these protein to have. I lack that, so it is difficult for me to follow.

It is interesting to note that he attributed the problem originally to a certain degree of unwillingness of physicists to learn specific biological details.

Becoming familiar with disciplinary language is one of the obstacles facing an interdisciplinary scientist (Golde & Gallagher 1999). Some physicists felt that biology is laden with specific terminology which takes time to grasp. This is illustrated in the following quotation from an interview with a veteran physicist from the group:

> At first the terminology was hard to understand. It took a little time. Once you grasp the terminology, [biology] starts to become relatively understood.

Challenges facing biologists in the group

A lack of strong quantitative training in the education of biologists has been reported recently (Bialek & Botstein 2004; National Research Council [NRC] 2003). One of the biologists in the group described the lack of depth in physics and some of its consequences saying:

> I feel that as the meeting progresses I understand [the physicists] better but I can not participate or suggest ideas. I never learned physics to such a degree. The most I can say is that I understand what they are talking about.

Another biologist, relatively new to the group but with extensive background in biology, described how she felt in one of the presentations which were overloaded with Mathematics:

> Once [the presenter] started to go over the equations and develop them, I didn't understand a thing [..] The theory is very complicated and to develop it… I understood the theory in general. I comprehended the intuition behind it but not beyond that [..] It's not that I don't want or can't do it. It's just that, first, it doesn't really interest me how he reached a certain equation. There is nothing I can do, right now I don't have the tools to deal with such questions.

The effects of the challenge of the lack of mathematical or physical knowledge, among the biologists in the group, are evident in some of the group meetings which were very physically oriented. In such group meetings more than 90% of the interactions were between physicists. The opposite did not happen in more biologically oriented group meetings, even tough the degree of participation was roughly equal to the percentage of physicists and biologists in the group.

Physicists learn how to build and use mathematical representations of physical processes (Van Heuvelen 1991). However, biological processes are more complex than physical ones (Mayr 1985; Rosenberg 1985). Biologists in the group often complained that they felt that some of the assumptions, or models presented by the physicists, are over simplistic or non-biological. This feeling was strongest among the biologists at the time of joining the group but it did not disappear over time. A biologist elaborated on the problems she had with the assumptions used by physicists saying:

> [The physicists] use assumptions which are incorrect in biology. I understand this however, they simplify things, give a general model and then they will go into something in more detail. I mean, they don't assume that the model is true biologically-wise.
> Q. And does it work ?
> No… many of the theories, they are theories based on mathematical models and they never tried them on organisms. [..] With many of the things which are more detailed it is OK. But many of the things are like evolutionary genomics and there, all their assumptions are simply beyond my ken. I completely do not understand these things. The first time I heard about them was in a group meeting given by [a computer scientist] on evolutionary genomics and I

> was like, 'how do you do evolution in the computer? I totally didn't understand your presentation' [laughs]

Group members' views on the disciplines of physics and biology

Tapping into the views of the group members on the nature of the disciplines of physics and biology may help to clarify the causes for some of the challenges discussed above. The views that follow were received from group members when they were asked to characterize biology and physics with an emphasis on comparing between them.

Group members' views about physics

In accordance with the literature (Becher 1990; Donald 1993; Donald 2002; Leonard et al. 1996), the physicists in the group described physicists as interested in finding general major basic principles. The group leader said:

> The interesting questions in physics are questions that deal with principles, questions that unify many systems and look at things in an abstract manner.

The tendency towards abstraction is thought to be ingrained into physicists as a part of their education as physicists. As previously suggested (Donald 1993), physics is indeed considered to be hierarchical by all of the group members. Thus, physical knowledge should be acquired in a specific sequential order. Mathematical insight is appreciated in physics (Donald 1993) and indeed, the hierarchical or layered nature of physics was attributed mostly to the mathematical aspects of physics. Most group members described the use of a small set of problems which are studied in great depth and act as a sort of a canon, as a central way of learning physics. Mapping new problems to canonical problems often adds important insights. It seems that mapping a problem to a familiar problem is a common and useful heuristic in physics, according to the group members' views.

Group members' views about biology

Not only was biological knowledge described as extensive, highly complex, incomplete and often ill-structured (Fisher et al. 2000), but also textbooks in biology were reported to supply unclear and loose definitions for theory (Gibbs & Lawson 1992). This combination may explain the views of group members that molecular biology is mostly a science of details about facts and methods, at least when compared to physics. Most group members share the view that classical molecular biologists are interested mostly in simple interactions.

The group members believe that the theoretical parts of biology are easy to learn when compared to physics and that learning them can be done through the use of text books. In accordance with the group members views that molecular biology is all about facts as described above, and with the tendency reported that textbooks center on facts and labels (Fisher et al. 2000; Gibbs & Lawson 1992), the group members believe that biology is relatively easy to learn when compared with physics. This stems from their belief that for learning biology reading and absorbing the facts from textbooks should be enough. This feeling, that learning biology is easier than learning physics was shared by all the group members, biologists and physicists alike.

The group members acknowledge that learning from books is good for learning the details of biological knowledge, but is not enough for developing proficiency or deep understanding in biology. Without learning the underlying organizing principles of biology and developing a well organized knowledge structure, physicists still experience the challenges reported above with the amounts of information they have to assimilate in lectures and group meetings. It seems that there is a clear distinction between theoretical knowledge and the more practical knowledge needed to conduct experimental research in biology. Physicists in the group believe that wetting their hands in a laboratory work is essential for their understanding. Although physicists in the group learn biology and most of them engage in laboratory work, there is still a reluctance to reach the full depth of knowledge in biology.

Discussion

In this study, the learning that occurs within an interdisciplinary scientific research group was studied. The group meetings of this group were observed and in-depth interviews were carried out with members of the group. Weekly group meetings were reported by the group members to be very beneficial to the scientific progress of this research group, especially due to the interdisciplinary nature of the group. The initial disciplinary identity that one acquires during his or her academic education was found here to strongly influence the way one acquires knowledge in and about other disciplines. The group members' views about the disciplines of biology and physics reveal some dichotomies between the two disciplines, which may explain the difference in challenges that biologists and physicists face when they begin to learn the disciplines they are unfamiliar with. The results of this study may facilitate interdisciplinary transitions of scientists, teachers and students at all levels.

The group members' views about the disciplines of biology and physics reveal some dichotomies between the two disciplines, which may explain the difference in challenges that biologist and physicists face when they begin to learn the disciplines they are unfamiliar with. The challenge of separating the wheat from the chaff, which physicists often described when dealing with biological knowledge, seem to be closely related to their view of biology as detailed and specific. Specific details are the opposite of principles and abstraction which are basic to the physicists. When everything is perceived as details, the conclusion that there is no wheat, only chaff is a natural one. What makes it even more difficult is that there are no easy mathematical values that can be attached to these details to help the process of simplification which physicists are using when faced with large amounts of data. The specificity of biological knowledge and its seeming lack of depth might further aggravate the challenge of a lack in biological conceptual knowledge. This lack can only be covered by learning but the motivation to learn often weakens when one feels that much of what there is to learn is very specific and not profound by itself.

On the other hand, the biologists in this study often expressed frustration regarding their lack of mathematical or physical training which they seldom encounter in their undergraduate studies. If we combine this with the deep hierarchy of mathematics that requires a relatively strict order of learning, some frustration seems inevitable. Physicists in the group often came up with models of biological systems that were based on various assumptions and neglections. The biologists in this study did not always agree with the logic of physicists on what may and should be neglected or assumed with regard to the analysis of biological systems, and some times regarded certain assumptions as "non-biological".

Systems biology can be viewed as having paradigmatic roots in systems thinking (Gutierrez et al. 2005). Most approaches to systems thinking agree that much of the art of system thinking involves the ability to represent and assess dynamic complexity (Linda & Sterman 2001). This requires mathematical skills as well as various systems thinking skills. Examples are the ability to understand how behavior of a system arises from the interaction of its agents over time, the ability to discover and represent feedback processes, the ability to identify nonlinearities and delays and to understand their impact (Linda & Sterman 2001). Biologists in this study reported some lack in mathematical skills and a difficulty with some of the general approaches used by physicists in the group. Physicists have prior experience with systems thinking and with the mathematics associated with it. Perhaps, a better understanding of the systems thinking skills related to systems biology, such as identifying components and the relationships between them, can facilitate the learning of the relevant mathematics. This should help biologists narrow the effect of this challenge without having to learn all the mathematics and mathematical tools that physicists acquired during their training in physics.

Recent calls suggested that undergraduate biology curriculum should undergo a transformation towards a more interdisciplinary curriculum which includes a more comprehensive quantitative training (Bialek & Botstein 2004; National Research Council [NRC] 2003). In agreement with these calls, We suggest that more emphasis will be put not only quantitative skills but also on systems thinking, since mathematical skills alone are insufficient for the application of systems thinking (Linda & Sterman 2001).

The interdisciplinary field of systems biology involves knowledge that stems from both the discipline of biology and the discipline of physics. Students of systems biology need to construct an interdisciplinary knowledge structure, based on the knowledge structures of their original discipline. The knowledge structure of those students can be described as progressing from synthetic interdisciplinary towards transdisciplinary (following Lattuca 2001). A synthetic interdisciplinary knowledge structure in systems biology may draw from the knowledge structures of biology and physics, thus containing elements from both knowledge structures without integrating them. However, a transdisciplinary knowledge structure in systems biology may share some similarity with the knowledge structures of physics and biology but it is mostly a new knowledge structure that is a result of merging the two original knowledge structures. It is evident that the group meetings facilitate this process but further research will be required in order to fully characterize the interdisciplinary identity of those involved in learning systems biology.

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